UNIVERSITY OF CALIFORNIA DIVISION OF AGRICULTURAL SCIENCES
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# Regional Efficiency in the Organization of Agricultural Processing Facilities: An Application to Pear Packing in the Lake County Pear District, California

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CALIFORNIA AGRICULTURAL EXPERIMENT STATION

Efficient organization of raw product assembly, processing, and shipping operations in an agricultural producing region is the empiric focus of this report. The specific application is to Bartlett pears produced in Lake County, California. The primary efficiency criterion is the minimization of the total District season cost of these operations.

The empiric solution is approached in several stages. Cost synthesis is used to estimate cost functions for the assembly, packing, cooling, and shipping operations. These results, along with estimates of future volume and location of pear production within the District, are then used in a modified linear programming transportation model to determine the optimum number, size, and location of processing and shipping facilities. An initial solution is based on a highly simplified model in which a uniform daily volume of product flow is assumed. The analysis then is extended to consider the effects of variation in daily volume of product received for processing as well as variation in total volume of annual District output. Using data concerning the structure of this industry, an assessment is made of the market–performance implications of the greatly increased concentration in the local industry that the cost–minimizing solutions suggest.

The empiric findings should provide useful guides in the organizational development of the industry over the next decade and in the specification of design variables that relate to operating practices and organization of facilities appropriate to the projected expansion of District output.

This report is one of a long series of studies of efficiency in agricultural processing operations. It is developed in the context of a modified theory of the firm and uses estimating procedures and empiric results developed in that series over a considerable time period. Spatial aspects of the optimizing models involve recent adaptations of traditional location theory. The empiric solutions employ simulation techniques to study cost–output relationships in operating situations not amenable to unique mathematical formulation, and sensitivity analysis is used to test the stability of empiric findings.

The theoretical framework and the analytical models of the study are adaptable to a wide range of problems involving efficiency in centralized processing and spatial distribution of farm production and processed output.

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# REGIONAL EFFICIENCY IN THE ORGANIZATION OF AGRICULTURAL PROCESSING FACILITIES: AN APPLICATION TO PEAR PACKING IN THE LAKE COUNTY PEAR DISTRICT, CALIFORNIA[1]

## I. INTRODUCTION

The numerous specific antecedents of this study extend to 1949 when a series of studies of costs and efficiency in the marketing of California fruits and vegetables was begun. The first studies in this series emphasized the selection of cost–minimizing technique and economies of scale in packing and shipping operations. An early publication (French, Sammet, and Bressler, 1956) presented adaptations of the theory of the firm essential to an understanding of the economics of modern production plant processes, empirical analyses of costs and efficiency in the packing and shipping of fresh pears in California, and a description of procedures in cost synthesis—–the principal analytical technique employed. The work was later extended to similar studies of the packing and shipping of fresh grapes, plums, lettuce, processed olives, and frozen fruits and vegetables and in subsequent applications to research on interregional competition and on industry structure and performance.[2]

In the decade during which this work was in progress, there was extensive effort, both privately and publicly supported, on the development of new technology with particular emphasis on type of container and materials–handling methods. Significant progress was made on the use of large bulk containers (of roughly 1,000 pounds capacity) in the assembly of field–run fruit and the transportation to canneries and in the use of bulk–fill fiberboard containers rather than hand–packed wood boxes for the shipment of fresh fruit. These developments prompted a restudy of pear packing with emphasis on the effects of new technique on costs and efficiency and economies of scale in assembly, packing, and shipping operations. This work also included an analysis of the optimum (cost–minimizing) number and location of plants in the Lake County Pear Producing District of California and of potential economies in the integration of packing and cold storage operations. This work was reported in a Ph.D. dissertation (Stollsteimer, 1961), and some of the results were published (Stollsteimer, 1963; Stollsteimer and Sammet, 1961).

The initial report from the 1961 study stimulated a series of comments. Hoch (1965) considered the likelihood that the spatial optimizing model used would yield a unique solution. Mathia and King (1962), Polopolus (1965), Sanders and Fletcher (1966), Warrack and Fletcher (1970a,b), and Chern and Polopolus (1970) reported on extensions of the basic model for application to problems of a different empirical nature, while Ladd and Halvorson (1970) and Toft, Cassidy, and McCarthy (1970) considered procedures for testing

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[1] Submitted for publication October 7, 1975.

[2] For example, see Courtney (1968), Dennis and Sammet (1961), French and Sammet (1954), Reed and Sammet (1963), and Smith (1961).

the model for sensitivity to changes in the values of strategic parameters. A comment on and extension of this type of analysis by Bobst and Waananen (1968) to a problem in the processing and marketing of milk raised the question as to the effects on industry structure and performance that would accompany the reduction in plant numbers indicated by cost–minimizing solutions.[1]

Subsequent to the 1961 study, important and unanticipated changes occurred in the pear industry of Lake County. The District became seriously affected by pear decline, a disease that previously had appeared in other California districts; and new and replacement tree plantings were made on a much closer spacing than formerly. In old orchards the new cultural practice frequently has involved the interset of new trees among existing trees. These developments, along with the emergence of interest among shippers in the District in the consolidation of existing plants, led to this third phase of study of packing and shipping operations in this District.

In the 1961 study of pear packing in Lake County, comparisons were made of numerous alternative techniques for performing tasks in the assembly and packing operations; the technique yielding least cost in relation to output rates in each plant stage was selected in developing assembly, packinghouse, and cold storage cost functions. In a 1972 survey of plant and assembly operations, techniques previously identified as most economical among available alternatives were found to be in general use; no major new techniques developed since 1961 were in evidence. Consequently, in the present study the cost analyses are greatly simplified through focusing the analysis only on presently prevailing technique. The exception to this rule is the development of plant and cold storage cost functions for the two types of shipping containers—the standard wood box and the fiberboard container. However, in many respects these alternatives represent different products requiring different production processes rather than different techniques for producing the same output.

By way of further simplification and economy in the present analysis, extensive use has been made of engineering data on physical input–output relationships in particular operations as well as use of adjusted cost functions developed in earlier studies in this series. Some aspects of the validity of these simplifications were considered in a recent paper by Sammet (1974).

## Statement of Problem

The particular focus of the present study is on analysis of costs and efficiency in shipping–point operations required in the marketing of fresh pears in a major California pear packing district (Lake County) under the current structure of factor prices. This includes determination of the number, size, and location of plants required for efficient performance of these functions at production levels anticipated in 1985 when existing plantings will be of mature, bearing age.[2] The fresh market shipping containers now in

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[1] Other applications of the basic model include Mathia and King (1962), Moore (1972), and Siebert (1964).

[2] For the empirical problem under consideration, cost minimization is appropriate as an objective function. Alternative formulations would include maximizing the present value of the future income stream derived from use of the facilities or minimizing the present value of future packing costs. Data limitations for future time periods make impracticable the use of these more complex models.

use (standard box and fiberboard carton) are regarded as alternative products, and the cost analyses are designed to demonstrate the cost relationships with respect to each. An assessment is made of the nature of the competitive relationships that would result from significant reduction in the present number of plants or firms.

The criterion applied in the cost and efficiency analysis is the minimization of total costs in the local pear marketing operations of this District. The problem solution requires the estimation under efficient organization of (1) cost–volume relationships for the assembly of fruit from orchard to plant and the grading, packing, and other operations performed in the packing plant as well as the precooling, storage, and shipping operations; (2) the cost–minimizing number and location of packing plants; and (3) the optimum integration of packing and storage capacities.

In the concluding section an appraisal is made of market structure in this sector of the California pear industry and of the implications as to market performance if further concentration should occur through reduction in number of pear marketing firms. The finding of a good approximation of a competitive market would make applicable the cost–minimizing solutions developed in the following sections.

## Empirical Setting of Analysis

The Lake County Pear District of California (hereafter referred to as Lake County or District), the locale of empirical analysis of this report, lies in a series of valleys almost entirely surrounded by mountainous terrain. The topography of the District thus creates a semi–isolated production region with well–defined boundaries.

The economy of the County is based largely on its agriculture, with some income derived from tourist trade. During the past five years, income derived from Bartlett pear production has averaged roughly $8 million annually or 57 percent of the total agricultural income of the County (Agricultural Commissioner, 1950–1971). The annual output of pears during this period averaged 46,000 tons which was about 20 percent of total state production (California Tree Fruit Agreement, 1971). Relative to 1950–1954, pear production in this region has increased about 12 percent, while reported bearing acreage has increased since 1950 by more than 90 percent (Agricultural Commissioner, 1950–1971). However, much of the increase in reported acreage appears to reflect multiple counting of existing acreage that has been interplanted either because of a shift in cultural practice or as a response to pear decline. Adjustment for multiple counting of some acreage provides an estimated total of approximately 6,000 acres of land in Bartlett pears in this District. With a large proportion of recently planted trees still to reach full bearing age, pear production in this area is expected to increase during the coming decade.

Relative to other California pear producing regions, Lake County ships a higher proportion of fruit to the fresh markets—on the average, 56.5 percent in Lake County compared with 17.4 percent in the state as a whole. Fresh shipments yield larger returns f.o.b. packinghouse than do cannery shipments; returns during the past five years averaged $273 per ton in fresh sales compared with $116 per ton for cannery fruit. Within limits permitted by contractual arrangements, shippers attempt to allocate fruit to fresh and processed markets so as to make returns to raw fruit (f.o.b. less local packing and storage costs) approximately equal in both markets. However, local handling and shipping costs are much higher for fresh than for cannery shipments as will be evident in later sections of this report.

In the shipment of fresh fruit, the proportions shipped in various standard containers have shifted markedly over recent years. Since 1959, the proportion of total California fresh shipment in the standard box has dropped from 75 to 47 percent, the proportion in Los Angeles lugs from 18 to 12 percent, and the proportion in San Francisco lugs from 5 percent to 0. Meanwhile, the proportion shipped in fiberboard cartons has increased since 1959 from less than 2 percent to more than 41 percent. Shipment of cannery fruit is entirely in the large pallet–bin container.[1]

The District currently is served by 10 separately operated packinghouses, 5 of which are grower–owned cooperatives. The remainder are essentially individual ranch–pack operations, although minor amounts of packing services may be performed for other growers. The capacity rates of operation in the cooperative plants range from approximately 40,000 to 110,000 pounds per hour (total fruit run, including cannery and culls). Capacity operating rates in the ranch–pack houses are much smaller. The packing season in the District varies in length from year to year but generally extends roughly over a 30–day period involving approximately 250 hours of packinghouse operation per season. Overtime operations, with premium wage payments for work in excess of 8 hours per day, are frequent occurrences; and there is some, but not general, use of 2–shift packinghouse operations.

In all the cooperative houses, precooling and cold storage facilities are provided for fresh–pack fruit. All shipments are by truck, there being no rail service in the District.

## II. ANALYTICAL FRAMEWORK

From the substantial body of economic theory that has been developed to deal with questions of the type considered in this study, the following elements are drawn upon in the formulation of an economic model for deriving the empiric solutions sought.

### Plant Costs in the Short and Long Run

With dependence on conventional assumptions of the theory of the firm (for simplicity stated for the case of a single output), the output Y of a production process may be expressed as

$$Y = f\ (X_1\ \ldots\ X_k\ X_{k+1}\ \ldots\ X_n) \qquad (1)$$

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[1] Net weights of fresh–pack containers now in use are the standard box, 48 pounds, and the carton, 36 pounds. Actual packed weights involve roughly 1 pound of overpacking so that normal shrinkage will not reduce net weight below the legal minimum. Net weights for the cannery bin are usually in the neighborhood of 1,000 pounds.

in which $X_1 \ldots X_k$ represent variable inputs used in conjunction with a fixed plant represented by $X_{k+1} \ldots X_n$. This equation, the production function, assumes maximum technical efficiency for the production method being used and so must indicate the maximum output attainable from every possible input combination, given the fixed plant.[1]

The price of each input ($V_i$), assumed to be a function of the quantity of all inputs used, is

$$\begin{aligned} V_1 &= V_1 \ (X_1 \ . \ . \ . \ X_n) \\ &\vdots \\ V_n &= V_n \ (X_1 \ . \ . \ . \ X_n). \end{aligned} \tag{2}$$

The cost of each input, equal to its price multiplied by the quantity used, is

$$C_i = V_i \ (X_1 \ . \ . \ . \ X_n) \ X_i. \tag{3}$$

Thus, total costs are equal to

$$TC = \sum_{i=1}^{n} C_i = \sum_{i=1}^{n} V_i \ (X_1 \ . \ . \ . \ X_n) \ X_i. \tag{4}$$

In the short run, only ($X_1 \ldots X_k$) are variables so the total cost function becomes

$$TC = A + \sum_{i=1}^{k} V_i \ (X_1 \ . \ . \ . \ X_n) \ X_i \tag{5}$$

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[1] This statement rests on the usual assumptions of the perfectly competitive version of the theory of the firm. These make profit maximization the goal of the individual firm and prescribe an operating environment for decision–makers involving perfect knowledge, production and sale in a system that is timeless and spaceless, and production processes that permit some degree of substitution among factors of production, between factors and output, and between products. Factors and products are assumed to be homogeneous and perfectly divisible; functions relating factors and products are assumed to be single valued and to have continuous first– and second–order derivatives. It is assumed that, through marginal adjustments to technical process alternatives and price relationships (both factor and product), costs will be minimized for any output of which the fixed plant is capable and, further, that there is a unique profit–maximizing rate of output. Factor prices for the individual firm are viewed as independent of quantity used, although factor prices may be functionally related to aggregate rate of use by the industry as a whole. For a full development of this theory, see, for example, Henderson and Quandt (1971).

where A represents the cost of the services provided by inputs which does not vary with the rate of output, that is, the cost of the services provided by inputs $X_{k+1} \ldots X_n$. These are fixed costs.

The outcome in the basic theory is that the cost of producing a given level of output $(\bar{Y})$ may be minimized by minimizing equation (5) subject to equation (1) being equal to $\bar{Y}$ and with the consequence that, for all factors of production, the individual ratios of marginal cost of output to the respective marginal physical productivities are all equal to each other and equal to the marginal cost of output.[1] Thus,

$$\frac{\partial TC/\partial X_1}{\partial Y/\partial X_1} = \frac{\partial TC/\partial X_2}{\partial Y/\partial X_2} = \ldots \frac{\partial TC/\partial X_n}{\partial Y/\partial X_n} = \frac{\partial TC}{\partial Y} \tag{6}$$

and, from these conditions, it is possible to specify the optimum value for each of the variable productive factors for any preassigned rate of output. The optimum amount of each factor is a function of the level of output and factor prices:

$$X_i = f^i\,[Y, V_1(X_1 \ldots X_n) \ldots V_k(X_1 \ldots X_n)] . \tag{7}$$

Substituting into equation (5) gives

$$\begin{aligned} TC &= A + \sum_{i=1}^{k} [V_i\, f^i\, Y, V_1(X_1 \ldots X_n) \ldots V_k(X_1 \ldots X_n)] \\ &= A + g\,[Y, V_1(X_1 \ldots X_n) \ldots V_k(X_1 \ldots X_n)]. \end{aligned} \tag{8}$$

This is a short–run cost function which specifies the minimum total cost of achieving any rate of output, given the constraints of the fixed plant and the implied production function. If the law of diminishing returns holds and $\partial V_i/\partial X_i > 0$, the short–run cost curves will have the conventional sigmoid form with respect to total costs and will be U–shaped in regard to average costs.

In the economic long run, it is assumed that all factors of production are variable, and so equation (1) may be written as

$$Y = f(X_1 \ldots X_n). \tag{9}$$

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[1] The solution also requires that the second–order differentials through which equation (6) is derived be positive; see Henderson and Quandt (1971).

This means that production technique also is variable, and the firm is free to choose a "plant" represented by particular values of selected $X_i$ of any size or design, given the technical knowledge available. Once each such plant is specified, a short–run cost function of the nature of equation (1) is established, and minimum total and average cost curves may be drawn. It is assumed that a series of such average cost curves arrayed in order of plant size or "scale" will reflect, first, decreasing minimum average cost as scale increases and, beyond an optimum minimum average–cost size, will reflect increasing minimum average cost. The lower (minimum average cost) bounds of an infinite series of such average cost curves define the long–run average cost curve.

In the descending section of this curve, economies of scale usually are attributed to more efficient use of certain factors of production in the larger plants, particularly those factors available only in relatively large, indivisible units; the use of production techniques which are physically feasible but uneconomical at low rates of output; or reduction in factor costs due either to real economies of large–scale purchasing or monopsonistic buying power of the large–scale firm. Diseconomies of scale are attributed to increasing difficulties in coordinating operations and to increases in product selling or factor procurement costs as plant size increases.

The estimation of short– and long–run cost curves is required in the following analysis. The short–run curves, whose segments define the long–run curve, will indicate the least–cost production technique at various rates of output and will provide the basis for cost comparisons among alternative types of output, while the economies–of–scale curve will influence the number of plants required to minimize the cost of producing a given level of industry output.

## Essential Adaptations

Efforts to apply the theory of the firm have led to numerous modifications of which the following are of importance in the empirical analyses of this study.

### Production and Cost Theory

In many empirical analyses of input–output and cost–output relationships, some of the assumptions of the basic theory have been found not to be applicable. Adaptations particularly important in this study involve (1) the introduction of a time dimension in variation in output per production period; (2) recognition of practices common in the organization of modern industrial processes—specifically, the use of a "production line" consisting of a series of coordinated production stages, each susceptible to cost–output analysis—and the segmentation of the production process through multiple installations of given production units in particular stages or through the expansion of plant size by the replication of similar production lines; (3) specific treatment of the limitations frequently found in factor substitution possibilities and of discontinuity in input–output relationships; and (4) consideration of the effects of the use of durable factors, including the need to maximize an objective function over time under conditions of uncertainty and risk with respect to future events.[1]

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[1] More complete discussion of these modifications will be found in French, Sammet, and Bressler (1956); Kutish (1953); Dean (1941); Brems (1952); and Jantzen (1924).

## Output Variation and Plant Flexibility

With the introduction of durable factors, uncertainty in regard to future values of planning variables assumes major importance in planning decisions concerning the degree of plant output flexibility to be provided and in the selection of production techniques. The limited treatment attempted in this study involves only the analysis of cost minimization with respect to varying production volume per period in which the planning options include (1) building a plant of sufficient size to handle peak volume in a fixed operating time; (2) varying output through adjustment in hours worked per period, e.g., through overtime or shift operation; and (3) providing for the temporary storage of incoming raw products during short periods of peak processing demand.

A solution to the problem of output variation and plant flexibility may be approached through determination of hourly plant capacity (k) and operating rule (r) with respect to hours of operation that will minimize the cost of handling a given total volume (X) of raw material arriving at the plant with a given seasonal distribution ($\pi$). This may be stated as follows:

$$\min_{k,r} \text{TPC} \; (k, r/X, \pi) = \min_{k,r} \; [A_k + \beta_{1k} H_{st} (k, r/\pi, X) + \beta_{2k} H_{ot} (k, r/\pi, X) + \text{TSSC} (k, r/\pi, X) + M (k, r/\pi, X)] \tag{10}$$

where

TPC = total season cost as a function of plant capacity k and operating rule r, given a total volume X of a raw product and a given seasonal distribution $\pi$

$A_k$ = fixed costs per season with plant having hourly capacity k

$\beta_{1k}$ = cost per hour of straight–time plant operation with plant of size k

$\beta_{2k}$ = cost per hour of overtime plant operation with plant of size k

$H_{st}$ = hours of straight–time operation as a function of k and r, given X and $\pi$

$H_{ot}$ = hours of overtime operation as a function of k and r, given $\pi$ and X

TSSC = total season storage cost as a function of k and r, given $\pi$ and X

and

M = cost associated with being unable to process a given quantity of raw material as a function of k and r, given $\pi$ and X.

Given $\pi$ and X, this function is minimized with respect to the controllable variables—k, size of plant, and r, operating rule which controls hours of operation. A minimum of this function can be obtained by minimizing over r for each value of k and selecting the minimum over k. This minimization process would be performed within a set of constraints dictated by the particular problem considered. A constraint as to maximum hours of operation per day or per week would be present in all such problems.

In actuality, neither $\pi$ nor X is a given value, but both are random variables. If the probability distributions of these variables are known or can be estimated from historical data, expected values for these variables can be introduced and the total season cost function converted to expected costs. The expected cost function would be minimized in the same way as the "sure" cost function. Lacking the distributions, a subjective evaluation as to the values of $\pi$ and X could be used to estimate the amounts and kinds of flexibility needed. However, in this situation the reliability of the estimates is completely unknown.

The problem considered in this model is characteristic of that faced by many manufacturing and processing firms, particularly in agriculture. Models applicable to situations involving only variations in supply between time periods or seasonal and/or total variations in demand can be formulated in a similar fashion.

**Factor and Product Flexibility.**—In addition to designing the plant to accommodate variations in output within and between time periods, plant designs which permit economical adjustment to changes in factor or product prices may be desired. The amount of this type of flexibility built into a specific plant will depend upon the discounted value of the expected gain from being able to shift to new products or factors. This expectation will be conditioned by the amount of uncertainty present in the factor and product markets in which the firm operates.

Like other types of flexibility, the ability to shift economically to new products or factors generally has a cost usually in terms of either higher investment costs for equipment or higher operating expenses with the nonspecialized equipment. In the restricted context of this study, examination of this problem involves only consideration of the cost effects of alternative forms of output, specifically, pears packed in standard boxes as compared with pears packed in fiberboard cartons.

## Location Theory

The selection of the optimum location for production activity is not explicitly treated in the pure marginal theory of the firm, but it can be argued that cost variations associated with different locations are implicitly contained in the production costs of the marginalist theory and that the least-cost production site will be sought out in the cost-minimization process. This, however, does not permit one explicitly to specify the effect of location on production costs, an omission dealt with in location theory.[1]

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[1] Present-day location theory is based to a large extent on the work of two German economists; see von Thunen (1875) and Weber (1929).

While the initial approach in this theory was aggregative for a producing region, a theory of location that deals with the location problem of individual producers was developed in Weber (1929) and extended in Isard (1960) and Losch (1954). Methods of problem solution in the framework of these theoretical concepts have since been developed. These involve various applications of programming and computer techniques which provide for consideration of multiple locations with respect to both production and processing of raw products and of consumption through systems of equations that represent the costs of production, processing, and transportation of given raw products originating in specified producing locations and transported to specified processing and consuming centers.

Through optimizing with respect to an objective function that specifies cost minimization, solutions may be obtained that satisfy the marginal criteria of the theory of the firm, i.e., that the cost–minimizing combination of inputs is obtained when the ratios of marginal unit cost to marginal physical productivity are equal for all factors of production. However, the system employed in contemporary spatial analysis explicitly includes the costs of processing and transportation and may, in the transshipment computational model (King and Logan, 1964), provide for optimization (cost minimization) of plant locations and numbers with respect to both sources of raw product and markets for final product.[1]

The extensions of the basic theory and the recent applications involving programming and computer techniques deal with significant limitations of the basic theory. Thus, the original concepts assume all points in the production region to be potential plant sites, while potential plant sites normally are limited to a select number of points adjacent to the existing transportation network. The distance functions thus are normally discontinuous in real problems, a situation that precludes the use of marginal calculus in solving for the optimum plant site. The basic model is also restrictive in the sense that the number of plants is not considered as a variable. The problems associated with discontinuous distance functions are adequately dealt with in the linear programming transportation model.[2] With adaptation, the linear programming technique is applicable to problems involving variations in plant numbers.

## A Working Model for Plant Numbers and Locations

One of the empiric problems considered in this study is the determination of the number, size, and location of plants which will minimize the combined assembly and processing cost of a fixed quantity of raw material produced at scattered production points. The following model adapts the economic theory described above to the empiric analysis required to solve this problem.

Given I raw material producing sites, each of which produces a quantity $X_i$ of a material to be assembled and processed at one of L possible plant locations located within

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[1] Other applications include Araji and Walsh (1969), Cobia and Babb (1964a,b), Miller and Henning (1966), Olson (1959), Von Oppen and Hill (1970), and Williamson (1962).

[2] For a discussion of the basic model and certain of its applications, see Gass (1969).

the raw material producing region at points adjacent to the existing transportation network,[1] what is the number, size, and location of plants which will minimize the assembly and processing cost of the total quantity of raw material produced per season in the region? Algebraically, this may be stated as follows:

$$\min_{J,L_J} TC \ (J, L_J) = \min_{J,L_J} \left( \sum_{j=1}^{J} P_j X_j + \sum_{i=1}^{I} \sum_{j=1}^{J} X_{ij} C_{ij} \right) \tag{11}$$

subject to $X_{ij} \geqslant 0$ and, hence, $X_j \geqslant 0$

where

$TC$ = total season processing and assembly costs

$P_j$ = unit processing cost in plant j ($j = 1 \ldots J \leqslant L$) located at $L_j$

$X_{ij}$ = quantity of raw material shipped from origin i to plant j located at $L_J$

$\sum_{i=1}^{I} X_{ij} = X_j$ = quantity of raw material processed at plant j

$C_{ij}$ = unit cost of shipping material from origin i to plant j located at $L_J$

and

$L_J$ = one combination of locations for J plants among the [L, J] possible combinations of locations for J plants, given L potential plant locations.

The procedures followed in minimizing equation (11) with respect to plant numbers and locations are affected by the presence or absence of economies of scale in processing and the way in which plant costs are influenced by plant location. The following four cases are considered.

## Case I—No Economies of Scale in Plant Operation: Plant Costs Independent of Location

If there are no economies of scale in processing—that is, $dP_j/dX_j = 0$—and if costs are independent of plant location—that is, $\Delta P_j/\Delta L_j = 0$—total processing costs are constant for any number of plants. Under these circumstances, total processing costs equal

[1] In a true long–run situation, the transportation network might also become a variable.

$$P \sum_{i=1}^{I} \sum_{j=1}^{J} X_{ij} = PX \tag{11a}$$

where P is the constant unit processing costs and X is the total quantity of material produced and processed per production period. Given this situation, equation (11) will be minimized by minimizing total transport costs represented by the second term of this equation. This is accomplished by shipping the production of each point of origin to the potential plant site for which $c_{ij}$ is a minimum. With no upper limit on plant size, the optimum number of plants and their location can be determined directly from a single scanning of the transportation cost matrix, $C_{ij}$, by rows (origins). The production of each origin is assigned to the potential plant site for which $c_{ij}$ is a minimum. A plant will be located at each potential site which minimizes transfer costs for at least one origin. The quantity processed at a given plant will be

$$\sum_{iL_j=1}^{IL_j} X_{iL_j}$$

where $IL_j$ specifies the set of origins for which a given plant location, $L_j$, minimizes transfer costs.

### Case II——No Economies of Scale: Plant Costs Dependent Upon Plant Locations

If there are no economies of scale but processing costs vary with plant location——that is, $\Delta P_j/\Delta L_j \neq 0$——the solution obtained by the above procedure may or may not be an optimum. The optimality of the solution obtained in case I may be checked as follows. Designate the transfer cost minimizing plant location for a given origin ($i = i'$) as $L_{j'}$. Check to see if there exists among the ($L - 1$) alternative plant locations one or more for which K, as defined below, is positive:

$$K = (P_j \mid L_j' - \underset{(j \neq j')}{P_j \mid L_j}) - (\underset{(j \neq j')}{c_{i'j} \mid L_j} - c_{i'j} \mid L_{j'}) \tag{11b}$$

where

$P_j \mid L_{j'}$ = processing cost at the transfer cost–minimizing plant site

$P_j \mid L_j$ $(j \neq j')$ = processing cost at each of the alternative plant sites

$c_{i'j} \mid L_j$ $(j \neq j')$ = transfer cost from origin $i'$ to each alternative plant location

and

$c_{i'j} \mid L_{j'}$ = minimum transfer cost from origin $i'$.

In order that K be positive, processing costs at site $L_j$ ($j \neq j'$) must be sufficiently less than at $L_{j'}$ to offset the increase in transfer costs which will accompany shipping origin i's raw material to a plant site other than $L_{j'}$. If there exists more than one plant site for which K is positive, the site having the largest positive value would be selected as the optimum destination for the material produced at i′. If this check is performed for each origin and the indicated shifts in the shipment pattern made, the transfer cost–minimizing solution specified above will be altered in a fashion which will yield an optimum solution for the case where $dP_j/dX_j = 0$ and $\Delta P_j/\Delta L_j \neq 0$. This solution could also be obtained by computing directly a combined plant and transportation cost matrix and applying the procedures indicated for case I to this combined cost matrix.

**Case III—Economies of Scale: Plant Costs Independent of Plant Locations**

It shall be assumed that plants at various locations use the same production technique and will therefore have the same total planning cost function. It will also be assumed that the form of this function is linear with a positive intercept. This particular functional form simplifies the solution of this problem and appears to be applicable to the cost–volume relationship in many plant operations.[1]

With this set of circumstances, the problem of minimizing equation (11) with respect to plant numbers, J, and locations, $L_J$, is one of a two–stage minimization and can be attacked in a stepwise fashion. The first step is to obtain a transfer cost function which has been minimized with respect to plant locations for each value of J. For any given number of plants, J, there are [L, J] possible combinations of locations, $L_J \mid J$.[2] For each combination of locations, $L_J$, there is a submatrix, $(C^*_{ij}) \mid L_J$, of the transportation cost matrix, $C_{ij}$. This matrix will be (I x J) with the entries in each of the J columns representing the transfer costs from each origin to one of the plant sites being considered. An (I x 1) vector, $(\overline{C_{ij}}) \mid J$, is obtained by scanning $(C^*_{ij}) \mid J$ by rows and selecting the minimum $c_{ij}$ in each row. Minimum total transfer costs with J plants at a specified set of locations $L_J$ is equal to the vector $(X_i)'$ whose entries $x_i$ represent the quantities of raw material produced at each of the I origins multiplied by $(\overline{C_{ij}}) \mid J$. For each value of J, there are [L, J] values of $(X_i)' \; (\overline{C_{ij}}) \mid J$. The minimum of these values over $L_J$ is a point on a transfer cost function minimized with respect to plant locations. This may be stated as follows:

$$\min_{L_J} \overline{TTC} \mid J = \min_{L_J} [(X_i)' \; \overline{(C_{ij})} \mid J] \tag{11c}$$

[1] The theoretical arguments in support of this statement have been presented earlier. Numerous empirical examples are available; see, for example, Dean (1941) or French, Sammet, and Bressler (1956). Linear plant cost functions simplify the analysis, but solutions are possible with nonlinear functions; also see King and Logan (1964) and Candler, Snyder, and Faught (1972).

[2] The symbol [L, J] denotes the total possible combinations of L items taken J at a time.

where

$\underset{L_J}{\text{Min}}\ \overline{TTC}$ = total transfer cost minimized with respect to plant location for each value of J = 1 ... L

$(X_i)'$ = a (1 x I) vector whose entries, $x_i$, represent the quantities of raw material produced at each of the I origins

and

$(\overline{C_{ij}}) \mid J$ = a vector whose entries, $c_{ij}$, represent minimum transfer cost between each origin and a specified set of locations, $L_J$, for J plants.

The shape of the transfer cost function minimized with respect to plant locations may be deduced from the expected signs of the first and second differences of this function with respect to plant numbers. The first difference of $\overline{TTC}$ with respect to plant numbers, J, will in general be negative or zero:

$$\frac{\Delta \overline{TTC}}{\Delta J} \leqslant 0. \tag{12}$$

The inequality will hold for all cases where there exists in $(C_{ij}^{**}) \mid L_J$——the submatrix of $C_{ij}$ representing transfer cost to plant sites not included in the current solution for a given J——an entry $c_{ij}^{**} < \overline{c_{ij}}$ for some i. If each of the potential plant locations is the minimum transfer cost destination for one or more origins, there will exist a $c_{ij}^{**} < \overline{c_{ij}}$ until all of the potential plant locations are included in the solution and $\Delta\overline{TTC}/\Delta J < 0$ for all $J < L$.

The second difference of $\overline{TTC}$ with respect to J is expected to be positive or zero:

$$\frac{\Delta^2 \overline{TTC}}{\Delta J^2} \geqslant 0\ . \tag{13}$$

A proof of this point for cases where the raw material is distributed uniformly over the plane could be developed relatively easily.[1] For the case of nonuniform density, which is the case being considered here, a proof appears to be very difficult. However, in numerous numerical examples——some of which were purposely rigged in ways which were felt to favor the occurrence of a negative or zero second difference——and in the actual problems solved in this analysis, the second difference was always found to be positive. Lacking a proof, one must conclude that there may exist particular cases where the second difference is negative; however, both intuition and experience indicate that the more general case is that of a positive second difference.

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[1] Lösch (1954, pp. 109–134) comes very close to providing such a proof.

With $\Delta\overline{TTC}/\Delta J < 0$ and $\Delta^2\overline{TTC}/\Delta J^2 > 0$, the shape of $\overline{TTC}$ will be as indicated in Figure 1. This function, TTC, is an envelope function to a set of total transfer cost points; the number of points is defined by

$$\sum_{J=1}^{L} [L, J]$$

with [L, J] points rising in a column above each point on the minimized transfer cost function corresponding to a particular value of J.[1]

## Processing Costs

With the constant marginal processing costs in any given plant and a positive intercept in the plant cost function, the total cost of processing a fixed quantity of raw material X will increase by an amount equal to the intercept value of the plant cost function with each increase in plant numbers. This is shown in Figure 2.

The addition of $\overline{TTC}$ and TPC yields a total assembly and plant cost function which has been minimized with respect to plant locations for varying numbers of plants. The number of plants which minimizes the combined assembly and processing costs depends upon the shapes of $\overline{TTC}$ and $\overline{TPC}$. In order that TC fall with an increase in plant numbers, J, the decrease in $\overline{TTC}$ must be greater than the increase in TPC. In the hypothetical example presented in Figure 2, the total quantity processed can be handled at minimum cost in two plants located at their optimal locations. The amount processed in each plant will be equal to

$$\sum_{i=1}^{I} X_{ij} = X_j$$

for each value of J.

## Case IV—Economies of Scale and Variations in Plant Costs With Locations

The more general case is one where the plant cost function is as specified, but $\Delta P_j/\Delta L_j \neq 0$. If this is true, total assembly and processing costs must be minimized simultaneously with respect to plant numbers and locations. This can be accomplished by adding to the minimum transfer cost for each $L_J \mid J = \overline{TTC} \mid L_J = (X_i)' (\overline{C_{ij}}) \mid L_J$ of the [L, J] possible locational combinations the processing costs associated with the particular allocation, given $L_J$. From the [L, J] values of the combined assembly and

[1] Hoch (1965) considered the question of whether a unique solution, as implied here, may generally be expected. While a nonunique solution was demonstrated in a contrived numerical example, it was concluded that such circumstances in a real problem would rarely be encountered.

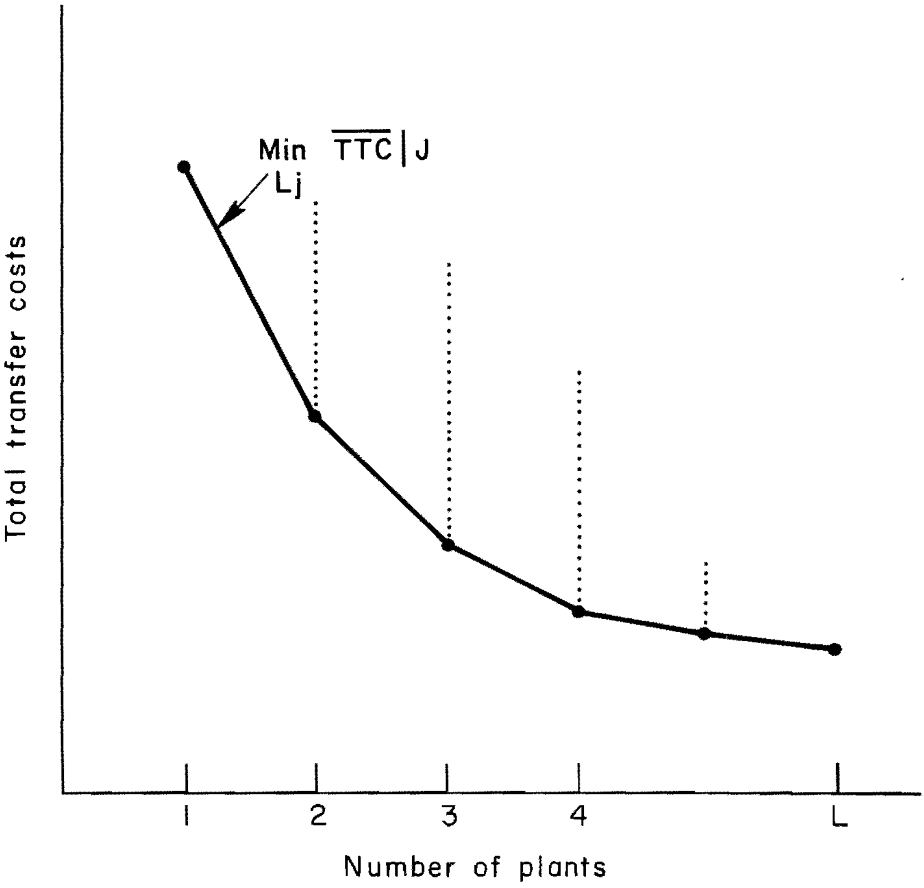


FIGURE 1. MINIMIZED TOTAL TRANSFER COSTS

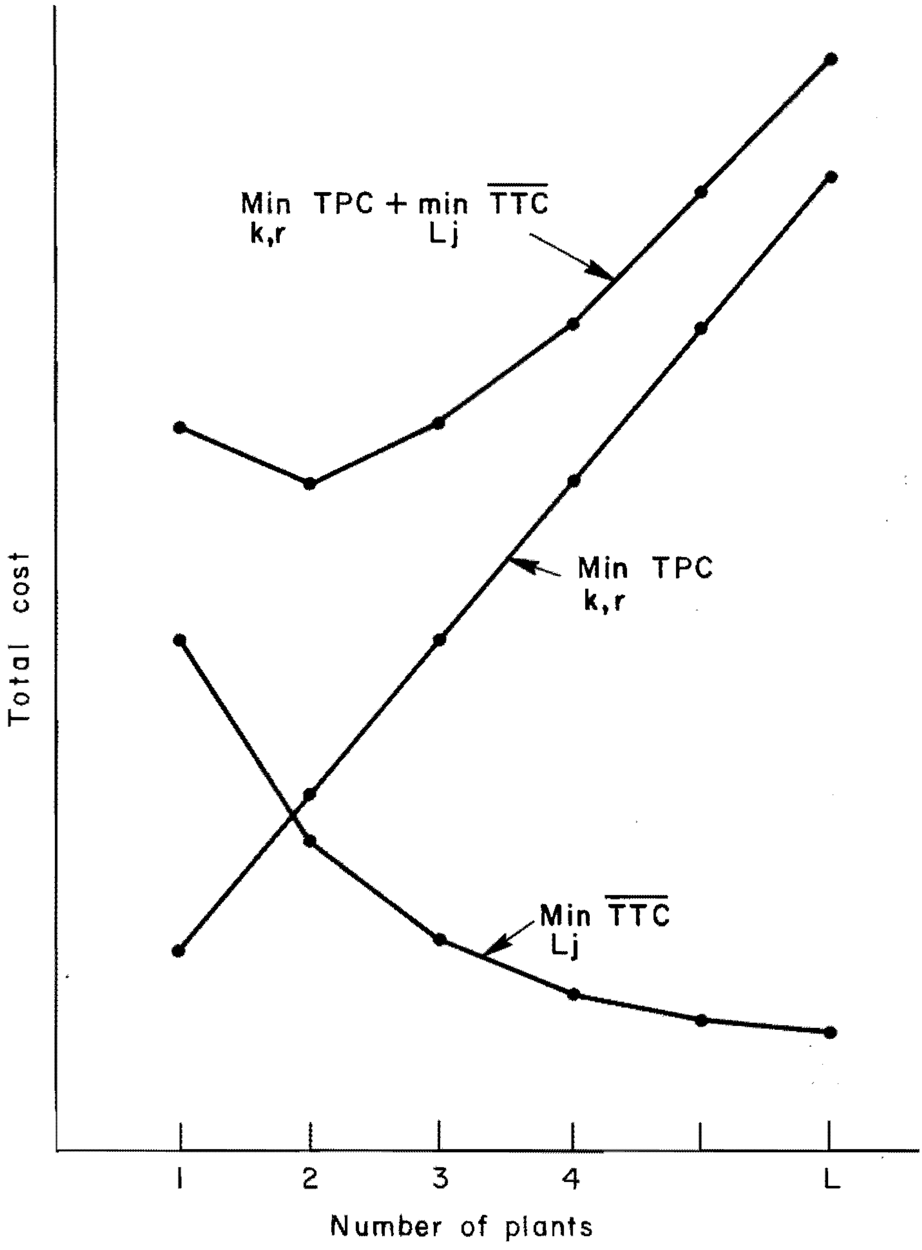


FIGURE 2. MINIMIZED TOTAL TRANSFER AND PLANT COSTS

processing costs, the minimum is selected as a point on the minimized total cost function. By performing these operations for each value of J = 1 ... L, the minimized assembly and processing cost function will be traced out.

**Characteristics of the Model**

The model presented here has many similarities to the linear programming transportation model but also has certain distinct properties. The linear programming transportation model is designed to determine the minimum–cost shipping pattern for supplying demands at a specified number of "sinks" at specified locations from a specified number of supply points also at specific locations. Thus, the linear programming model is directly applicable only to situations in which plant numbers and locations are specified. The model presented here comprises a set of LP programs, automated to select the least cost among repeated solutions with both plant numbers and locations permitted to vary.

As presented, the model is basically long run in nature. However, modifications of this model may be used in studies of the reorganization of existing systems, e.g., reduction in number of existing plants or determining the optimum size and location of new plants in the expansion of existing capacity. This would be accomplished by introducing the presently existing plants into the system with the appropriate upper limits on plant capacity and the appropriate short–run cost functions. A model of this type also is applicable to similar problems in distribution, for example, the supplying of a number of different consuming districts from a varying number of plants located over the consuming region.[1]

## III. EMPIRIC METHODOLOGY

The empiric objectives of this study involve primarily the use of cost synthesis to estimate long–run cost functions for the assembling, packing, storing, and loading operations which together comprise the producing–area activities in the marketing of pears. These cost functions are then applied in a modified version of the transportation model of linear programming and the assignment model to determine the cost–minimizing number, size, and location of plants. Determination of the optimum degree of plant–operating flexibility is studied within the framework of the queuing model of operations research.[2]

Since cost synthesis is the primary estimating technique used and is the principal means through which the basic data are introduced, the operations studied, procedure of cost synthesis, and major data sources are described briefly below.

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[1] For example, see Courtney (1968).

[2] The analytical procedures referred to are described in Sammet (1958, pp. 110–227); French, Sammet, and Bressler (1956); and Churchman, Ackoff, and Arnoff (1957, pp. 391–415).

## Operations Studied

The product flow diagram shown in Figure 3 indicates the general nature of the production process and the material flows considered in this analysis. The diagram represents numerous separate operations grouped in a series of operating stages. Successive stages are connected by transportation links, and there is temporary storage at many points.

Assembly operations begin in the orchard where full containers of fruit are loaded on the vehicles used in highway transportation operations. Orchard operations also include the distribution of empty picking containers. Highway transportation includes hauling full containers to the plant and returning empty containers to the orchard.

Plant operations begin with the receiving stage where field–run fruit is unloaded from the assembly vehicles, weighed, tallied, and moved either to cold storage for later processing or to dumping stations where the fruit is dumped on conveyors leading to grading and sizing equipment. In the grading stage the field–run fruit is separated into several categories or grades. The separate flows of fruit in each grade are then handled on specialized process lines. From 60 to 90 percent of the field–run fruit will normally qualify for packing for the fresh market. The remainder falls in other grades such as cannery fruit and culls. In many cases a portion of the fruit meeting the minimum tolerance for shipping to fresh markets is diverted to cannery grade.

After grading and (for the fresh market fruit) sizing, the fruit in each grade is packaged. Packaging material is fed into the production line at the points where needed. Following the packaging operation, the clerical work necessary to maintain packout, inventory, and shipping records is performed. Containers for the fresh market fruit are usually size stamped; and, finally, the fresh–pack boxes are lidded. Packed fruit is palletized for movement into cold storage or to the truck used for shipment to the fresh market. Cannery fruit is packaged in bins. Forklift trucks are used to move bins or palletized boxes or cartons to temporary storage or to the highway vehicle.

## Forms of Output

Field–run fruit normally is separated into four grades: packing fruit, No. 1 cannery grade, No. 2 cannery grade, and culls. The No. 1 cannery fruit is essentially the same as packing–grade fruit, with the exception that skin blemishes removable with a one–eighth inch peel are permitted in the cannery grade. The No. 2 cannery grade consists of fruit which is somewhat inferior in shape, size, or surface texture. As a minimum, fruit in No. 2 cannery grade must produce one good half. The primary use of No. 2 cannery fruit is in the production of strained baby foods. Culls are the lowest grade of pears and have little value other than for animal feed, although some of the lower grade fruit is dried.

Grades for packed fruit are defined in the Agricultural Code (State of California, 1969) and by the U. S. Agricultural Marketing Service (1955). Minimum standards for Bartlett pears are established by the California Tree Fruit Agreement (1972). The grade packed in a given plant on a given day is determined by both the current market conditions and the quality of the raw fruit delivered to the plant. With sufficient sorting, almost any given day's receipts can be used to make a particular grade, but generally the grade packed is tempered to the raw product being received.

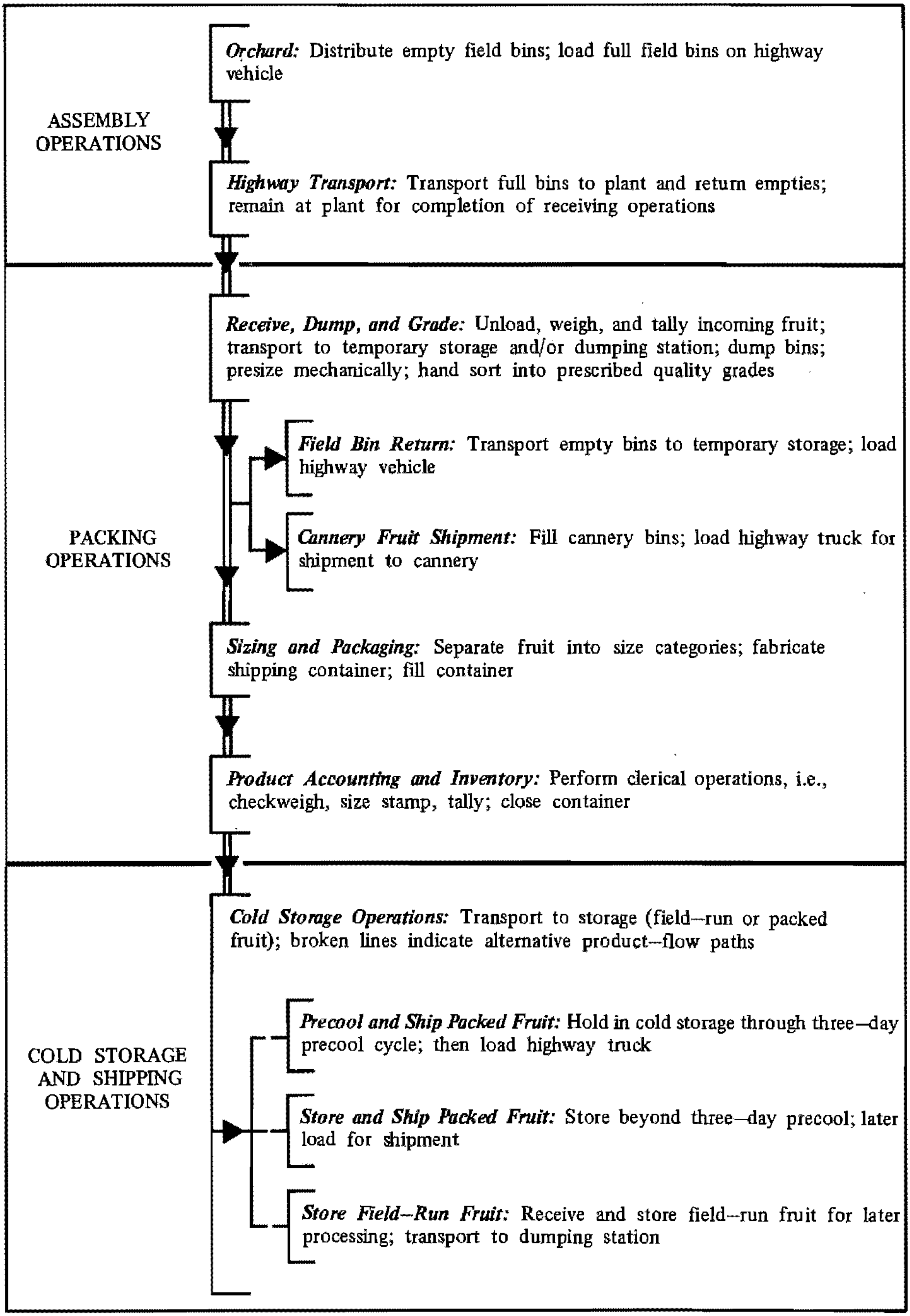


**FIGURE 3. PROCESS FLOW DIAGRAM: PEAR PACKING—ASSEMBLY AND PLANT OPERATIONS**

## Cost Synthesis

Data sources and estimating procedures used in synthesizing cost relationships in the assembly, packing, storing, and loading operations are described briefly below.

### Production Standards for Labor

In cost synthesis, production standards are required for labor on the various jobs involved in carrying out the operations performed at each stage. If more than one production technique is to be considered, a labor production standard must be established for each. These standards are defined as the continuous output rate which a reasonably efficient worker could maintain over time. For most operations the standards used in this analysis fall between the average and the highest observed rates of output.

Time and production data were used to determine the amount of working time required to perform each of the tasks carried out at a given stage. An allowance for unavoidable delay, rest periods, and personal time is added to working time to obtain the total time required for a given job. In this analysis, 15 percent of total working time was allowed for nonproductive activities for in–plant operations––reflecting a higher percentage of nonproductive time––and 20 percent of total time for orchard operations. Working time plus nonproductive time yields total time required per unit which can be used to determine the output standard per worker per hour.

With a given production technique and output rate, the estimated number of workers required on each job is the ratio of output rate to production standard rounded to the next higher whole number. Hourly labor costs with each production technique at various rates of output are determined by applying appropriate wage rates to the indicated labor requirements. For plant operations the wage rates used are those specified in the 1972 collective bargaining agreement between packinghouse workers and the industry in northern California, including employer–paid benefits. Labor costs for orchard operations are based on the prevailing wage rates for orchard labor in northern California during the 1972 pear harvest season, including allowance for employer–paid benefits.

### Equipment

Capacity output rates for equipment are estimated through analysis of time study data, interviews with plant managers, and study of equipment manufacturers' specifications. Installed plant and cold storage equipment replacement charges are based upon manufacturers' 1959 quoted prices for delivery in northern California plus contractors' estimates of installation costs, adjusted to the 1972 price level by the use of appropriate Bureau of Labor Statistics (BLS) wholesale price series indices.

### Sources of Data for Production Standards

The first in this series of studies (French, Sammet, and Bressler, 1956) emphasized packinghouse operations and provided standards for use in the present analysis on all operations for which production technique and plant operations then observed remain unchanged. Through the use of work measurement procedures described above, additional production standards were developed in the beginning phase of the present analysis (Stollsteimer, 1961). These data relate to new types of operations associated with (1) the substitution of bins for lugs in the assembly and cannery shipment operations; (2) the introduction of the fiberboard, bulk–fill carton for fresh fruit shipment; and (3) the addition of precooling and cold storage facilities operated integrally with the packinghouse. In regard to the cold storage operations, engineering data were used to estimate equipment requirements; and these were converted to costs through the application of price data obtained from refrigeration engineering firms. Replacement costs for cold storage buildings are based mainly on engineering estimates of construction labor and materials required for buildings of specified size and type and on 1972 prices.

Production standards for handling bins in the orchard are based upon studies in 13 California apple orchards and 1 California pear orchard. In–plant handling of bins was studied in two California pear packing plants and two apple packinghouses in Washington. Production standards for the various jobs involved in using bulk–fill packing methods are based on time studies made over the course of two operating seasons in 1 California pear packing plant and studies during a single year in 13 California citrus houses.

As noted above, certain of the production standards used in this analysis are based on time study data obtained by observing operations involving fruit other than pears. However, these sources were used only for those jobs in which the operations performed and the expected unit time requirements are the same as in pear packing or assembly operations.

### Total Annual Cost Estimation

Production standards of the type described above are used to estimate labor and equipment requirements in relation to rate of output for each stage and each alternative production technique considered. Appropriate labor and fixed and variable equipment cost rates are applied to these physical requirements to determine total task, stage, and plant costs with any given method of operation.

## IV. PACKINGHOUSE LONG–RUN COSTS

In this section long–run packinghouse cost functions are developed which, with the cold storage and assembly cost functions estimated in Sections V and VII, respectively, are used to determine the optimum number and size of plants and their locations within the producing region. The estimated packinghouse cost relationships include all outlays associated with the receiving of field–run fruit and processing materials, in–house grading and packing operations, fresh–pack containers, product shipment, and related general activities. Cost functions are estimated for the two types of output most commonly produced, namely, a fresh fruit package involving a manually place–packed standard box of 48 pounds net weight and a machine–fill fiberboard carton of 36 pounds net weight. For convenience the principal variables involved in the empiric analysis are defined in summary form in Appendix A.

## Estimating Procedure

The nature of the packinghouse organization and the sequence of jobs and operating stages involved in the packing operations are described briefly in Section III. As indicated there, the technical organization of these operations is well established, and there is no need in the estimation of the long–run cost function to consider alternative techniques. The cost–synthesis estimating procedure applied in this section and also described in Section III is thus greatly simplified.

In the interest of brevity, presented in this section is only an illustration of the estimating procedure and the final summary results. More details as to the calculations and references to sources of methodology are given in Appendix B.

The plant–organizational and cost–estimating models used in the estimation of packinghouse costs are described in Table 1 which identifies—–with respect to the broad categories, "operating stage" and "general cost"—–the individual operating stage and general cost components involved. With respect to each operating stage and general cost component, the table also indicates the product flow and time variables to which operating costs are related. These variables are specified as follows:

$V_p$ = volume of fruit packed for fresh shipment (1,000 pounds per hour)

$V_c$ = volume of cannery and cull fruit run (1,000 pounds per hour)

$V_t$ = total packinghouse output (1,000 pounds per hour)

$= V_p + V_c$

and

H = hours of packinghouse operation per season.

## Development of Long–Run Cost Functions

The development of a generalized cost function that relates the above variables to total packinghouse cost per season is approached by (1) assigning selected values to the product–flow variables, synthesizing hourly variable and annual fixed equipment costs with respect to individual operating stages, and summing across stages to obtain a set of cost points, each corresponding to specific values of the product–flow variables,[1] and (2) using least–squares regression analysis to estimate the average relationships between total season packinghouse cost and the product–flow variables.

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[1] Individual operating stages are defined so as to make them, for practical purposes, independent of other stages so far as cost effects are concerned. The model thus permits a simple aggregation of costs in individual stages to obtain total packinghouse costs.

TABLE 1

Operating Stages, General Cost Components, and Cost Function Variables
Fresh Pear Packing, Lake County, California, 1972

| Operating stage or cost component | Cost function variable |
|---|---|
| Operating stage | |
| Sample grading of incoming fruit[a] | $V_t$, H |
| Dumping | $V_t$, H |
| Grading[b] | $V_t$, $V_c$, H |
| Packing[c] | $V_p$, H |
| Cannery and cull fruit packaging | $V_c$, H |
| In-house transportation | $V_t$, $V_p$, $V_c$, H |
| Truck loading | $V_p$, H |
| General costs | |
| Direct supervision and miscellaneous labor | $V_t$, H |
| Miscellaneous equipment | $V_t$ |
| Administrative costs | $V_t$ |
| Building costs | $V_t$, $V_p$ |

[a]For sample grading of incoming fruit, $V_t$ = total packinghouse output in 1,000 pounds per hour and H = hours of packinghouse operation per season.

[b]For grading, $V_c$ = volume of cannery and cull fruit run (1,000 pounds per hour).

[c]For packing, $V_p$ = volume of fruit packed for fresh shipment (1,000 pounds per hour).

**Single–Product Cost Equations**

Using the above procedure, long–run cost equations are developed separately for place– and bulk–fill operations as described below. In Table 2 estimated hourly variable costs and annual fixed costs at the 1972 price level are presented for the dumping stage. The operations performed involve the machine dumping of fruit from assembly bins onto a conveyor leading to the grading equipment. The operation is fully automated except for the placement of full bins on the feed conveyor and the removal of empty bins with forklift equipment. A machine operator is required at each such station, however, to correct faulty operation and to make periodic adjustments in dumping speed so as to harmonize dumping rate with rate of throughput in succeeding operating stages. The relevant cost function variables are total output per hour, $V_t$, and, implicitly, hours of operation per season, H.

Using the appropriate production standards for labor and equipment, crew and equipment requirements in relation to selected rates of product flow per hour were estimated. These physical quantities were converted to costs by the application of 1972 cost rates. Such calculations were made for a total of 24 preselected output rates although, for reasons of brevity, only 12 are shown in the table.

Cost calculations, similar to those illustrated in Table 2, were made with respect to each operating stage. For packinghouses using place–pack procedures, the estimated hourly variable cost and annual fixed cost in each operating stage for selected output rates are shown in Table 3. Similar results for packinghouses using bulk–fill procedures are reported in Table 4. Since for some of the stages involved––e.g., grading and packing––selection of particular values for the volume variables requires specification of the division of total product flow between packed fruit and cannery and cull fruit ($V_p$ and $V_c$, respectively), the data in Tables 3 and 4 are based on the preselected proportion of 70 percent packed fruit and 30 percent cannery and cull fruit. Similar calculations were made for 50, 60, 80, and 90 percent packed fruit.[1]

In addition to costs related to specific operating stages, Table 1 identifies four categories of general packinghouse costs that must be included in the long–run cost functions. A simplified procedure was used for estimating these components, and the results are given for selected output rates in Tables 3 and 4. These estimates were obtained through application of appropriate cost indices to component cost relationships developed in the earlier studies (Stollsteimer, 1961; French, Sammet, and Bressler, 1956). The basic relationships, along with a description of the adjustment procedure used, are contained in Appendix B.

Summing across individual operating stages and including the direct supervision and miscellaneous labor component of general packinghouse costs yields total hourly variable cost in relation to the specified rates of total product flow. Summing annual fixed costs across individual operating stages and including the appropriate general cost components gives total annual fixed cost in relation to rate of total product flow. These results also are presented in Tables 3 and 4.

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[1] In the interest of conciseness, the tables for other than 70 percent packed fruit are omitted.

TABLE 2

Estimated Labor Requirements, Hourly Variable Costs, and Annual Fixed Charges in Dumping Stage of Fresh Pear Packing Operations by Pounds of Fruit Dumped Per Hour Lake County, California, 1972

| Dumping rate | Number of dump operators required | Hourly variable cost | | | Annual fixed equipment charges[c] | | | |
|---|---|---|---|---|---|---|---|---|
| | | Labor[a] | Power and repairs[b] | Total | Fruit distribution belts | Bin dumper | Water tank and dryer | Total |
| 1,000 pounds per hour | | dollars per hour | | | dollars per year | | | |
| 10 | 1 | 2.74 | 0.49 | 3.23 | 114 | 488 | 623 | 1,225 |
| 20 | 1 | 2.74 | 0.49 | 3.23 | 114 | 488 | 623 | 1,225 |
| 30 | 1 | 2.74 | 0.49 | 3.23 | 114 | 488 | 623 | 1,225 |
| 40 | 2 | 5.48 | 0.90 | 6.38 | 228 | 976 | 623 | 1,827 |
| 50 | 2 | 5.48 | 0.90 | 6.38 | 228 | 976 | 623 | 1,827 |
| 60 | 2 | 5.48 | 0.90 | 6.38 | 228 | 976 | 623 | 1,827 |
| 70 | 3 | 8.22 | 1.25 | 9.47 | 342 | 1,464 | 1,246 | 3,052 |
| 80 | 3 | 8.22 | 1.25 | 9.47 | 342 | 1,464 | 1,246 | 3,052 |
| 90 | 3 | 8.22 | 1.25 | 9.47 | 342 | 1,464 | 1,246 | 3,052 |
| 100 | 4 | 10.96 | 1.47 | 12.43 | 456 | 1,952 | 1,246 | 3,654 |
| 110 | 4 | 10.96 | 1.47 | 12.43 | 456 | 1,952 | 1,246 | 3,654 |
| 120 | 4 | 10.96 | 1.47 | 12.43 | 456 | 1,952 | 1,246 | 3,654 |

[a]Based on wage rate of $2.42 per hour, plus a 13.2 percent allowance for fringe benefits.

[b]Electric power estimated at 3 cents per motor horsepower; repairs estimated at 0.5 percent of equipment replacement cost per 100 hours of operation.

[c]Based upon estimated annual charges for depreciation, interest, repairs, taxes, and insurance of 13.37 percent of replacement costs; see Appendix Table B-6, *infra*, pp. 126 and 127, for list of equipment replacement costs and annual fixed charges.

Source: Calculated on basis of labor and equipment requirements in Stollsteimer (1961).

TABLE 3

Estimated Stage and Total Hourly Variable and Annual Fixed Costs by Rate of Output for Place-Packing Pears When 70 Percent of Total Fruit Received Is Fresh Packed, Lake County, California, 1972

| Item | Total packinghouse output rate, $V_t$[a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
| | dollars per hour | | | | | | | | | | | |
| Variable costs | | | | | | | | | | | | |
| Operating stage | | | | | | | | | | | | |
| Dumping | 3.23 | 3.23 | 3.23 | 6.38 | 6.38 | 6.38 | 9.47 | 9.47 | 9.47 | 12.43 | 12.43 | 12.43 |
| Grading | 26.65 | 30.75 | 53.88 | 58.96 | 66.79 | 89.71 | 97.52 | 107.76 | 130.89 | 143.59 | 143.59 | 164.18 |
| Packing | 189.08 | 371.60 | 554.11 | 736.63 | 919.14 | 1,101.66 | 1,284.18 | 1,466.69 | 1,649.21 | 1,831.72 | 2,014.24 | 2,196.76 |
| Cannery and cull fruit packaging | 2.73 | 2.80 | 2.99 | 3.06 | 5.64 | 5.77 | 5.84 | 6.04 | 8.62 | 8.69 | 8.88 | 9.01 |
| In-house transportation | 6.39 | 9.35 | 12.31 | 15.05 | 18.01 | 23.93 | 26.67 | 29.63 | 33.28 | 36.02 | 38.98 | 44.90 |
| Truck loading | 3.01 | 3.01 | 6.02 | 6.02 | 9.03 | 9.03 | 12.04 | 12.04 | 12.04 | 15.05 | 15.05 | 18.06 |
| Inspection of incoming fruit | 2.50 | 5.00 | 7.50 | 9.99 | 12.49 | 14.99 | 17.49 | 19.99 | 22.49 | 24.98 | 27.48 | 29.98 |
| General cost | | | | | | | | | | | | |
| Direct supervision and miscellaneous labor | 16.53 | 21.97 | 25.28 | 30.72 | 31.53 | 34.04 | 46.22 | 46.22 | 49.53 | 54.96 | 55.76 | 58.27 |
| Total variable costs | 249.12 | 447.71 | 665.32 | 866.81 | 1,069.01 | 1,285.51 | 1,499.43 | 1,697.84 | 1,915.53 | 2,127.44 | 2,316.41 | 2,533.59 |
| | dollars per year | | | | | | | | | | | |
| Fixed costs | | | | | | | | | | | | |
| Operating stage | | | | | | | | | | | | |
| Dumping | 1,225 | 1,225 | 1,225 | 1,827 | 1,827 | 1,827 | 3,052 | 3,052 | 3,052 | 3,654 | 3,654 | 3,654 |
| Grading | 303 | 322 | 644 | 644 | 909 | 966 | 1,212 | 1,288 | 1,610 | 1,610 | 1,610 | 1,932 |
| Packing | 3,826 | 5,400 | 6,973 | 8,547 | 10,121 | 11,695 | 13,269 | 14,842 | 16,416 | 17,990 | 19,564 | 21,138 |
| Cannery and cull fruit packaging | 503 | 675 | 1,154 | 1,325 | 1,496 | 1,805 | 1,977 | 2,460 | 2,635 | 2,810 | 3,293 | 3,605 |
| In-house transportation | 3,203 | 4,817 | 6,432 | 8,350 | 9,965 | 12,208 | 14,138 | 15,727 | 17,985 | 19,914 | 21,528 | 23,762 |
| Inspection of incoming fruit | 114 | 114 | 221 | 221 | 221 | 221 | 221 | 221 | 221 | 221 | 221 | 221 |
| General costs | | | | | | | | | | | | |
| Miscellaneous equipment | 938 | 1,616 | 2,294 | 2,971 | 3,649 | 4,327 | 5,004 | 5,682 | 6,360 | 7,037 | 7,715 | 8,393 |
| Administration | 4,693 | 8,383 | 12,073 | 15,763 | 19,453 | 23,143 | 26,833 | 30,523 | 34,213 | 37,903 | 41,593 | 45,283 |
| Building | 6,179 | 8,309 | 10,440 | 12,570 | 14,701 | 16,831 | 18,961 | 21,092 | 23,222 | 25,353 | 27,483 | 29,614 |
| Total fixed costs | 20,984 | 30,861 | 41,456 | 52,218 | 62,342 | 73,023 | 84,667 | 94,887 | 105,714 | 116,492 | 126,661 | 137,602 |

[a]$V_t$ = 1,000 pounds per hour; total fruit pack = 70 percent of total packinghouse output rate.

Source: Computed.

TABLE 4

Estimated Stage and Total Hourly Variable and Annual Fixed Costs by Rate of Output for Bulk-Fill Pear Packing When 70 Percent of Total Fruit Received Is Fresh Packed, Lake County, California, 1972

| Item | Total packinghouse output rate, $V_t$ [a] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
| | dollars per hour | | | | | | | | | | | |
| Variable costs | | | | | | | | | | | | |
| Operating stage | | | | | | | | | | | | |
| Dumping | 3.23 | 3.23 | 3.23 | 6.38 | 6.38 | 6.38 | 9.47 | 9.47 | 9.47 | 12.43 | 12.43 | 12.43 |
| Grading | 25.65 | 30.75 | 53.88 | 58.96 | 66.79 | 89.71 | 97.52 | 107.76 | 130.89 | 143.59 | 143.59 | 164.18 |
| Packing | 112.21 | 222.22 | 332.24 | 442.26 | 552.27 | 662.29 | 772.30 | 882.32 | 992.34 | 1,102.35 | 1,212.37 | 1,322.38 |
| Cannery and cull fruit packaging | 2.73 | 2.73 | 2.92 | 2.92 | 5.43 | 5.63 | 5.63 | 5.76 | 8.34 | 8.34 | 8.47 | 8.67 |
| In-house transportation | 6.39 | 9.35 | 12.09 | 15.27 | 20.75 | 23.71 | 26.67 | 33.06 | 36.02 | 38.76 | 44.68 | 47.64 |
| Truck loading | 3.01 | 3.01 | 6.02 | 6.02 | 9.03 | 9.03 | 12.04 | 15.05 | 15.05 | 15.05 | 18.06 | 18.06 |
| Inspection of incoming fruit | 2.50 | 5.00 | 7.50 | 9.99 | 12.49 | 14.99 | 17.49 | 19.99 | 22.49 | 24.98 | 27.48 | 29.98 |
| General cost | | | | | | | | | | | | |
| Direct supervision and miscellaneous labor | 16.53 | 21.97 | 25.28 | 30.72 | 31.53 | 34.04 | 46.22 | 46.22 | 49.53 | 54.96 | 55.76 | 58.27 |
| Total variable costs | 172.25 | 298.26 | 443.16 | 572.52 | 704.67 | 845.78 | 987.34 | 1,119.63 | 1,264.13 | 1,400.46 | 1,522.84 | 1,661.61 |
| | dollars per year | | | | | | | | | | | |
| Fixed costs | | | | | | | | | | | | |
| Operating stage | | | | | | | | | | | | |
| Dumping | 1,225 | 1,225 | 1,225 | 1,827 | 1,827 | 1,827 | 3,052 | 3,052 | 3,052 | 3,654 | 3,654 | 3,654 |
| Grading | 303 | 322 | 644 | 644 | 909 | 966 | 1,212 | 1,288 | 1,610 | 1,610 | 1,610 | 1,932 |
| Packing | 3,966 | 5,147 | 6,329 | 7,511 | 8,692 | 9,874 | 11,055 | 12,237 | 13,419 | 14,600 | 15,782 | 16,964 |
| Cannery and cull fruit packaging | 503 | 503 | 983 | 983 | 983 | 1,463 | 1,464 | 1,776 | 1,951 | 1,954 | 2,266 | 2,749 |
| In-house transportation | 3,214 | 4,840 | 6,779 | 9,024 | 10,963 | 12,588 | 14,188 | 17,401 | 19,027 | 20,945 | 23,200 | 24,826 |
| Inspection of incoming fruit | 114 | 114 | 221 | 221 | 221 | 221 | 221 | 221 | 221 | 221 | 221 | 221 |
| General costs | | | | | | | | | | | | |
| Miscellaneous equipment | 938 | 1,616 | 2,294 | 2,971 | 3,649 | 4,327 | 5,004 | 5,682 | 6,360 | 7,037 | 7,715 | 8,393 |
| Administration | 4,693 | 8,383 | 12,073 | 15,763 | 19,453 | 23,143 | 26,833 | 30,523 | 34,213 | 37,903 | 41,593 | 45,283 |
| Building | 6,179 | 8,309 | 10,440 | 12,570 | 14,701 | 16,831 | 18,961 | 21,092 | 23,222 | 25,353 | 27,483 | 29,614 |
| Total fixed costs | 21,135 | 30,459 | 40,988 | 51,514 | 61,398 | 71,240 | 81,990 | 93,272 | 103,075 | 113,277 | 123,524 | 133,636 |

[a] $V_t$ = 1,000 pounds per hour; total fruit pack = 70 percent of total packinghouse output rate.

Source: Computed.

Separate functions that relate hourly variable or annual fixed costs and volume of fresh–packed and cannery fruit run per hour can each be represented by a mathematical expression of the following form:

$$C = b_0 + b_1 V_p + b_2 V_c \tag{14}$$

where

$C$ = cost in dollars

$V_p$ = volume of fruit packed for fresh shipment (1,000 pounds per hour)

and

$V_c$ = volume of cannery and cull fruit run (1,000 pounds per hour).

When equations of the above type are fitted to the complete set of cost–volume points for all rates of output and for all proportions of packed and cannery fruit considered, the following results (with HVC denoting hourly variable cost and AFC, annual fixed cost) are obtained:

*Place–Pack Operation*

$$HVC = 34.4 + 28.5 V_p + 3.0 V_c \tag{15}$$

$$AFC = 9{,}725 + 1{,}166 V_p + 825 V_c \tag{16}$$

*Bulk–Fill Operation*

$$HVC = 29.8 + 18.2 V_p + 3.0 V_c \tag{17}$$

$$AFC = 10{,}333 + 1{,}122 V_p + 808 V_c . \tag{18}$$

The coefficient of determination for each of the equations exceeds 0.99. Since the synthesized cost points do not satisfy the stochastic assumption of least–squares regression, the statistic cannot be interpreted in the usual sense of percentage of variation in the dependent variable (HVC or AFC) associated with variation in the independent variables ($V_p$ and $V_c$). However, the statistic can be interpreted as a measure of the "goodness of fit" of each estimated regression equation and the synthesized cost points. In each of the four cases, the equation estimated does fit the synthesized cost–volume points well.

For each type of packinghouse operation, the above equations can be converted into a planning–cost relationship which is used to estimate total season costs in relation to given rates of output, percentage of total fruit packed, and hours of operation. This involves multiplying the hourly variable cost equation by H, hours of packinghouse operation per season, and adding the two equations to obtain:

*Place–Pack Operation*

$$TSPC = 9{,}725 + 1{,}166\ V_p + 825\ V_c + 34.4\ H + 28.5\ V_pH + 3.0\ V_cH \quad (19)$$

*Bulk–Fill Operation*

$$TSPC = 10{,}333 + 1{,}122\ V_p + 808\ V_c + 29.8\ H + 18.2\ V_pH + 3.0\ V_cH \quad (20)$$

where

TSPC = total season packinghouse cost (dollars)

H = hours of packinghouse operation per season

$V_p$ = volume of fruit packed for fresh shipment (1,000 pounds per hour)

and

$V_c$ = volume of cannery and cull fruit run (1,000 pounds per hour).

Equations (19) and (20) are defined as long–run packinghouse total cost functions.

**Multiple–Product Cost Equations**

It is also of interest to estimate cost relationships in a multiproduct setting which is the common practice. This is accomplished as follows.

Ideally, the multiple–product cost equation might be estimated by expanding the set of estimated total cost points to reflect varying proportions of bulk– and place–packed output. For convenience, a simpler procedure was used which rests on the observation that in practice the packing stage, with only minor exceptions, operates independently of the other operating stages and general cost components and that, in combination, the bulk– and place–pack lines operate independently of each other. This is evident in comparison of Tables 3 and 4 which show that––with the exception of the packing, cannery and cull fruit packaging, in–house transportation, and truck loading stages––costs in all other operating stages and for the general cost components are, for a given rate of output, the same in both place–pack and bulk–fill operations. Of the four stages in which costs differ between the two types of packinghouses, the differences are trivial except for the packing stage. Consequently, equations (15), (16), (17), and (18), along with the packing–stage cost equations shown in Appendix B, are used to develop an estimating equation to approximate costs in packinghouses which produce both a place– and bulk–fill pack as multiple products.[1]

The multiple–product equation was developed by first subtracting the appropriate packing–stage cost equation from equations (15), (16), (17), and (18) to obtain fixed– and variable–cost equations for both place–pack and bulk–fill operations net of packing costs. Since the remaining coefficients of the corresponding equations for each type of packinghouse were of almost the same magnitude, the coefficients of corresponding terms of the two equations were averaged. The results are a single fixed–cost equation and a single hourly variable–cost equation that express the relationship between total packinghouse costs, exclusive of the packing stage, and rate of output. Next, a variable–cost equation relating total costs in the packing stage to volume of fruit packed was obtained by adding to the derived equations described above the separate packing–stage, variable–cost equations for the place– and bulk–fill methods.[2]

A similar procedure was followed for the packing–stage, fixed–cost equations. Finally, the variable– and fixed–cost equations for all packinghouse costs, exclusive of the packing stage, were combined with the separate variable and fixed–cost equations for place– and bulk–fill packing. Multiplying the resulting variable–cost equation by H and adding the fixed– and variable–cost equations gives:

$$\begin{aligned} TSPC = {} & 10{,}029 + 966.2\ V_p + 816.5\ V_c + 32.1\ H + 2.0\ V_pH \\ & + 3.0\ V_cH + 183.6\ V_p^P + 162.0\ V_p^B + 26.5\ V_p^PH + 16.2\ V_p^BH \end{aligned} \tag{21}$$

subject to

$$V_p^P + V_p^B = V_p$$

[1] A packinghouse having both place–pack and bulk–fill packing capability is referred to as a "combined" operation.

[2] The constant term of the derived equation was not obtained by summing the constant terms of the individual equations; rather, the two constant terms were averaged to obtain the constant term for the derived equation. The loss of accuracy in this procedure is insignificant.

where

$V_p^P$ = volume of fruit place–packed (1,000 pounds per hour)

$V_p^B$ = volume of fruit bulk–filled (1,000 pounds per hour)

TSPC = total season packinghouse cost (dollars)

H = hours of packinghouse operation per season

$V_p$ = volume of fruit packed for fresh shipment (1,000 pounds per hour)

and

$V_c$ = volume of cannery and cull fruit run (1,000 pounds per hour).

Equation (21) is the long–run cost function for facilities that provide for packing fruit using both place–pack and bulk–fill procedures.

Equation (21) can be reduced to a close approximation of either of the single–product equations from which it was derived by substituting $V_p^B = 0$ or $V_p^P = 0$. As demonstrated below, the resulting equations yield cost estimates for given values of the volume variable that are remarkably close to those obtained by direct application of equations (19) and (20).

Equations (19), (20), and (21) provide the basis for determining the least–cost type of packinghouse for specified values as to rate of output, hours of operation, and percentage of fruit dried. The process is simplified by restricting the range of operating conditions to those similar to actual conditions. Such conditions may be defined as rate of total packinghouse output ($V_t$) $\geqslant$ 5,000 pounds per hour and hours of operation and proportion of fruit packed within the following limits:

$$100 \leqslant H \leqslant 400$$

$$0.5 \leqslant P_p \leqslant 0.9$$

where H is hours of packinghouse operation per season and $P_p$ is proportion of fruit packed.

When rate of output, hours of operation, and proportion of fruit packed are at their lower limits, the following results are obtained by substitution in equations (19), (20), and (21):

*Place–Pack Operations*

$$TSPC = \$26{,}018$$

*Bulk–Fill Operations*

$$TSPC = \$23{,}438$$

*Combined Operations* [1]

$$TSPC = \$24{,}715.$$

If in equation (21) $V_p^B$ is set equal to zero, then the equation can be used for approximating costs in place–pack operations. When the substitution is made and costs are calculated under the stated conditions, TSPC = \$26,030 which is nearly the same as TSPC calculated using equation (19). Similarly, with $V_p^P = 0$ in equation (21), TSPC = \$23,401 which closely approximates the TSPC = \$23,438 obtained using equation (20). Thus, bulk–fill operations yield lowest cost when total packinghouse output, hours of operation, and proportion of fruit packed are set at their lower limits. It follows that, for any given rate of total output and with hours of operation and proportion of fruit packed set at their lower limits, bulk–fill operation is lower in total season cost than place–pack or combined operations.

## Effect of Change in Operating Variables and Type of Pack

The effect of increasing either hours of operation or proportion of fruit packed on total season processing cost is obtained by differentiating the three long–run cost functions with respect to hours of operation and proportion of fruit packed. Differentiation with respect to proportion of fruit packed requires that this variable be explicitly introduced into the equations. Since volume of fruit packed ($V_p$) plus the volume of cannery and cull fruit are, by definition, equal to total volume ($V_t$), the proportion of fruit packed can be introduced as a variable in the cost functions by substituting $V_t$ for $V_p$ and $V_c$ and premultiplying the coefficients of $V_p$ by $P_p$––the proportion of fruit packed––and the coefficients of $V_c$ by $(1 - P_p)$. Making these substitutions, the long–run packinghouse cost functions become:

---

[1] This specific estimate of costs for combined operations is based on 50 percent of fruit place–packed and 50 percent bulk–filled.

*Place–Pack Operations*

$$TSPC = 9{,}725 + P_p (1{,}166) V_t + (1 - P_p) (825) V_t + 34.4 H + P_p (28.5) V_tH + (1 - P_p) (3.0) V_tH. \tag{22}$$

*Bulk–Fill Operations*

$$TSPC = 10{,}333 + P_p (1{,}122) V_t + (1 - P_p) (808) V_t + 29.8 H + P_p (18.2) V_tH + (1 - P_p) (3.0) V_tH . \tag{23}$$

*Combined Operations*

$$\begin{aligned} TSPC = {} & 10{,}029 + P_p (966.2) V_t + (1 - P_p) (816.5) V_t + 32.1 H \\ & + P_p (2.0) V_tH + (1 - P_p) (3.0) V_tH + P_p (183.6) QV_t \\ & + P_p (162.0) (1 - Q) V_t + P_p (26.5) QV_tH \\ & + P_p (16.2) (1 - Q) V_tH \end{aligned} \tag{24}$$

where

$Q$ = proportion of total fruit packed using place–pack procedures

$(1 - Q)$ = proportion of total fruit packed using bulk–fill procedures

TSPC = total season packinghouse cost (dollars)

$P_p$ = proportion of fruit packed

$V_t$ = total packinghouse output (1,000 pounds per hour)

$= V_p + V_c$

and

$H$ = hours of packinghouse operation per season.

The partial derivatives of these equations with respect to $P_p$ are as follows:

*Place–Pack Operations*

$$\frac{\partial TSPC}{\partial P} = 341\ V_t + 25.5\ V_tH \tag{25}$$

*Bulk–Fill Operations*

$$\frac{\partial TSPC}{\partial P} = 314\ V_t + 15.2\ V_tH \tag{26}$$

*Combined Operations*

$$\frac{\partial TSPC}{\partial P} = 311.7\ V_t + 21.6\ QV_t - 1.0\ V_tH + 10.3\ QV_tH. \tag{27}$$

These results indicate that, for all rates of output and lengths of operating season within the ranges specified, the rate of cost increase associated with an increase in the proportion of fruit packed is more rapid in place–pack operations than in bulk–fill operations. The rate–of–cost increase for combined operations is intermediate to the rates of the two specialized operations.

The partial derivatives of the long–run cost equations with respect to H, hours of packinghouse operation per season, are as follows:

*Place–Pack Operations*

$$\frac{\partial TSPC}{\partial H} = 34.4 + (3.0 + 25.5\ P_p)\ V_t \tag{28}$$

*Bulk–Fill Operations*

$$\frac{\partial TSPC}{\partial H} = 29.8 + (3.0 + 15.2\ P_p)\ V_t \tag{29}$$

*Combined Operations*

$$\frac{\partial TSPC}{\partial H} = 32.1 + (3.0 + 15.2\ P_p + 10.3\ P_pQ)\ V_t. \tag{30}$$

These derivatives indicate that, for all relevant proportions of fruit packed and any given rate of total packinghouse output, costs increase least rapidly with increasing hours of operation in bulk–fill and most rapidly in place–pack operations.

It is evident that, for the entire range of operating conditions considered, use of bulk–fill procedures exclusively yields lower total costs than does use of either a combination of bulk–fill and place–pack procedures or use of place–pack procedures exclusively. This conclusion is based on (1) the result that, when hours of operation and percentage of fruit packed are at their lower limits, bulk–fill operation yields lower total costs than does either combined or place–pack operation and (2) costs rise more rapidly in combined and place–pack as compared with bulk–fill operation as hours per season and proportion of fruit packed are increased from their lower limits.

## V. COLD STORAGE OPERATIONS

The storage of pears generally serves three major goals of the firm which are to (1) retard ripening rates through precooling the fruit prior to shipment; (2) provide flexibility in packing operations, including adjustment in length of packing season through deferral of packing operations and possible expansion of the harvest season by drawing on more remote producing areas; and (3) extend the marketing season so as to achieve optimal rates of deliveries to markets. To deal with the last of these objectives requires specification of the temporal demand for fresh pears and of the functions that relate the effects of actions of the firm in time t to revenue functions applicable in periods (t + 1) . . . (t + n). However, this is a task not to be undertaken here where the focus is on the interrelationships between storage and packing costs.

### Cold Storage Costs

Costs in the cold storage operation consist of the fixed and variable costs of the refrigeration equipment and the storage building. The costs of the materials handling involved in loading and unloading the storage might also be considered a part of storage costs, but in this analysis they are included as part of the in–plant transportation costs.

Estimation of the cost relationships needed is approached through the synthesis of equations for (1) estimating refrigeration capacity in relation to storage loading rates, (2) relating refrigeration capacity to equipment costs, and (3) expressing building costs as a function of floor area and storage capacity. The basic estimating module is a storage room with an 18–foot clearance under the ceiling, designed for forklift materials handling, and having 6,300 square feet of floor area (75′ x 84′). Cost–size relationships are developed by expanding the number of such modules and estimating total cost as each increment is added.

### Refrigeration Capacity Required

The refrigeration load per time period in a given storage is measured in "tons" and consists of two components.[1] The first, the precooling load, is related to the cooling of warm incoming fruit. This load depends on the amount and temperature of fruit placed in storage per day and its temperature after cooling. The second component, the holding load, is the rate of heat removal required to maintain the product in storage at the desired temperature. The holding load is a function of the amount of fruit in storage and its respiration rate, the temperature of the ambient air, the holding temperature in the storage room, and the structural characteristics and dimensions of the storage building.

Given specification of the above variables, the refrigeration load in a given storage receiving fruit at any given rate can be estimated from data available in various published sources.[2] The procedure followed is one of utilizing known heat flow characteristics for the materials involved to estimate the total amount of heat which must be removed from the storage per time period. Equation (31), given below, was developed in this manner and is designed to satisfy the following conditions:

1. Storage room maintained at 32° F.
2. Temperature of the ambient air, 100° F.
3. Incoming fruit reduced from 90° F. to 32° F. within 72 hours.
4. Storage buildings of wood frame construction with 6–inch–thick fiber glass insulation in the walls and 10–inch thickness in the ceiling; the floor, 6–inch concrete on a gravel base.

The estimating procedure, detailed in Appendix C, yields the following:

$$R = 0.173\ L + 0.050\ SC_1 + 0.017\ SC_2 \tag{31}$$

where

$R$ = refrigeration load (tons of refrigeration)

$L$ = storage loading rate (1,000 pounds of fruit per day)

$SC_1$ = precool storage capacity (1,000 pounds of fruit)

and

$SC_2$ = storage capacity in excess of precooling requirements (1,000 pounds of fruit), i.e., $SC_2$ = total storage capacity, 3L.

---

[1] A ton of refrigeration is equal to the heat absorbed by 1 ton of melting ice per day or 228,000 Btu per day.

[2] For details and references, see Appendix C, *infra*, pp. 128ff.

This equation can be used to approximate the refrigeration load under the operating conditions specified and in relation to selected values for storage capacity and loading rate.

### Refrigeration Equipment Costs

Equipment requirements and costs are a direct function of the refrigeration load. Compressors and evaporators, which are the major equipment items, are normally rated in tons of refrigeration. These units and the amount of piping and wiring required per ton of refrigeration reflect some economies as storage capacity increases.

Estimated replacement costs for refrigeration equipment per ton capacity in relation to the size of the refrigeration system—including equipment installation, piping, and wiring—are based on equipment prices and installation charges obtained from refrigeration equipment manufacturers and contractors. They can be expressed as a function of refrigeration capacity by the following equations:

$$I_r = 900 - 0.352\ R \qquad R < 300 \tag{32}$$

$$I_r = 794 \qquad R \geqslant 300 \tag{32a}$$

in which $I_r$ represents total investment in dollars per ton of refrigeration.

Equation (32) is based on 1959 price data, adjusted to the 1972 level by application of a composite index consisting of a weighted average, based on the BLS wholesale price index for "pumps and compressors" (adjusted to 1959 = 100) and similar price indices for on–site materials and labor.[1]

### Variable Equipment Costs

The principal variable cost is for electrical power. This is computed from motor horsepower requirements, estimated to equal 1.25 (R) where R is the refrigeration load. Power costs are estimated on the basis of $0.02 per hour per motor horsepower for electricity. In addition, variable repairs are estimated as 0.1 percent of equipment replacement costs per 100 hours of operation.

### Cost Equations

The data presented above were used to develop the following equations for estimating equipment replacement and hourly variable costs of refrigeration in relation to refrigeration load:

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[1] For development of this index, see Appendix C, *infra*, pp. 128ff.

$$I_r = 7{,}200 + 770\ R \qquad R < 300 \tag{33}$$

$$I_r = 794\ R \qquad R \geqslant 300 \tag{33a}$$

$$HVC_r = 0.07 + 0.033\ R \qquad R < 300 \tag{34}$$

$$HVC_r = 0.034\ R \qquad R \geqslant 300 \tag{34a}$$

where

$I_r$ = investment cost of refrigeration equipment (dollars)

$HVC_r$ = variable cost for refrigeration equipment per hour of storage operation (dollars)

and

$R$ = refrigeration load (tons of refrigeration).

Equation (33) was developed by using equation (32) to generate a series of total fixed equipment cost points in relation to refrigeration load and fitting to them a linear regression line; equation (34) was obtained by application of the unit repair costs given above to equation (33) and combining the result with hourly power cost = (0.02) (1.25) R.

## Building Costs

A planning–cost relationship for building construction was developed by determining input requirements and costs in one–, two–, and three–module units of the storage building previously described and then generalizing the resulting relationship between floor area and construction cost.

Engineering estimates of requirements in various construction categories and 1972 prices for materials and labor are the basis of estimates for the major components of building costs. The costs for minor elements were computed by using appropriate BLS wholesale price indices to adjust estimates originally made in 1959.[1] These estimates show total construction costs to have a closely linear relationship to floor space and to reflect very modest economies of scale as indicated in the equation

$$I_b = 1{,}870 + 8{,}410\ A \tag{35}$$

where $I_b$ is total investment cost of cold storage building (dollars), and A is storage floor space (1,000 square feet).

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[1] For details, see Appendix C, *infra*, pp. 128ff.

In equation (35), floor space requirements for the storage of a given quantity of fruit are estimated, in relation to type of container, by means of the following coefficients:

| *Type of container* | *Square feet of floor space required per 1,000 pounds of fruit* |
|---|---|
| Standard box | 4.40 |
| Bulk–fill carton | 5.88 |
| Field bins | 3.18 |

### Storage Costs Per Operating Season

For later applications the foregoing equations must be expressed in terms of fixed or variable costs per season. This is done by computing annual charges for refrigeration equipment at the rate of 13.4 percent of replacement cost and for the storage building at the rate of 9.0 percent.[1] Season total variable costs are obtained by multiplying variable cost per hour by hours operated per season. By these means, equations (32), (33), and (34) become:

$$AFC_r = 965 + 103.2\ R \qquad R < 300 \tag{36}$$

$$AFC_r = 106.4\ R \qquad R \geqslant 300 \tag{36a}$$

$$AFC_s = 168 + 756.9\ A \tag{37}$$

$$SVC_s = 0.07\ H_s + 0.033\ RH_s \qquad R < 300 \tag{38}$$

$$SVC_s = 0.034\ RH_s \qquad R \geqslant 300 \tag{38a}$$

where

$AFC_r$ = annual fixed cost for refrigeration equipment (dollars)

$AFC_s$ = annual fixed cost for storage building (dollars)

$SVC_s$ = total variable storage cost per season (dollars)

and

$H_s$ = hours of storage operation per season.

[1] Percentage annual charge for refrigeration equipment includes depreciation, 6.7; fixed repair, 1.5; taxes, 1.0; insurance, 1.0; and interest on investment, 3.2 percent; total, 13.4 percent. For the storage building, the corresponding rates are depreciation, 2.5; fixed repair, 1.8; taxes, 1.0; insurance, 0.6; and interest on investment, 3.1 percent; total, 9.0 percent.

In equation (35), floor space requirements for the storage of a given quantity of fruit are estimated, in relation to type of container, by means of the following coefficients:

| *Type of container* | *Square feet of floor space required per 1,000 pounds of fruit* |
|---|---|
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$$AFC_r = 965 + 103.2\ R \qquad R < 300 \tag{36}$$

$$AFC_r = 106.4\ R \qquad R \geqslant 300 \tag{36a}$$

$$AFC_s = 168 + 756.9\ A \tag{37}$$

$$SVC_s = 0.07\ H_s + 0.033\ RH_s \qquad R < 300 \tag{38}$$

$$SVC_s = 0.034\ RH_s \qquad R \geqslant 300 \tag{38a}$$

where

$AFC_r$ = annual fixed cost for refrigeration equipment (dollars)

$AFC_s$ = annual fixed cost for storage building (dollars)

$SVC_s$ = total variable storage cost per season (dollars)

and

$H_s$ = hours of storage operation per season.

[1] Percentage annual charge for refrigeration equipment includes depreciation, 6.7; fixed repair, 1.5; taxes, 1.0; insurance, 1.0; and interest on investment, 3.2 percent; total, 13.4 percent. For the storage building, the corresponding rates are depreciation, 2.5; fixed repair, 1.8; taxes, 1.0; insurance, 0.6; and interest on investment, 3.1 percent; total, 9.0 percent.

Planning–cost equations for cold storage operations over the respective refrigeration capacity ranges specified are obtained by summing over the above components of total storage costs. The results are as follows:

$$TSSC = 1{,}133 + 103.2\ R + 756.9\ A + 0.07\ H_s + 0.033\ RH_s \qquad R < 300 \quad (39)$$

$$TSSC = 168 + 106.4\ R + 756.9\ A + 0.034\ RH_s \qquad R \geqslant 300 \quad (39a)$$

where

TSSC = total season storage costs (dollars)

R = refrigeration load (tons of refrigeration)

and

A = storage floor space (1,000 square feet).

Equation (39) is directly applicable to a "steady state" situation in which R, A, and $H_s$ are predetermined constants. The equation is modified in Section X for use in analyses in which these terms are treated as interrelated variables subject to randomly determined rates of delivery for field–run fruit and specified operating rules.

## VI. PLANT COSTS: PACKINGHOUSE PLUS COLD STORAGE

The long–run cost equations developed in the preceding sections for packinghouse and cold storage operations (equations 22, 23, 24, and 39) are in each case linear with a positive intercept on the cost axis, and so each reflects economies of scale as size of operation increases. To illustrate the nature of these economies and the difference in level of costs with place– as compared with bulk–fill packing and also to provide an element of analysis in the solution for optimum number, size, and location of plants given in Section IX, long–run cost equations that combine packinghouse and cold storage cost relationships are developed below.

For these purposes particular relationships between cold storage and packing capacities and specific values for other key variables are selected. This involves the specification that the packinghouse operates at a uniform rate per hour—–8 hours or less per day, six days per week, and a total of 250 hours per season; or, alternatively, that it operates two 8–hour shifts per day and a total of 400 hours per season.[1] Under these specifications, no premium overtime wage costs are incurred. The cold storage facility operates continuously through the season and for three additional days at the end of the packing

[1] The estimates for a two–shift operation are based on the assumption that no wage–rate differential is applied to the second shift.

season to permit completion of the precooling and shipping operations—a total of 37, 24–hour days, equal to 888 hours, with the 250–hour packinghouse season; and 32, 24–hour days, equal to 768 hours, with a 400–hour packinghouse season.[1] The precooling and holding time in cold storage is three days, and so the storage capacity required is three times the daily volume of fruit run. Of the total fruit received, 65 percent is packed, and 35 percent is diverted to cannery fruit and culls.

Application of the above specifications to the generalized packing and cold storage cost equations results in their simplification to two–variable equations that relate total season cost to total volume run per hour. Such equations for a place–pack, bulk–fill, and combination plant (packing 50 percent each of place–pack and bulk–fill containers) are given in Table 5 for season lengths of 250 and 400 hours. In presenting these equations the refrigeration capacity constraints specified in equation (39) are translated into equivalent quantities of fruit run per hour, $V_t$, through the use of equation (31). This is done by substituting the limiting value of refrigeration required capacity ($R = 300$) in equation (31) and noting that in this instance $SC_2 = 0$, $SC_1 = 3L$, and $L = (0.65\ V_t)\ 8$.

In the simplified form presented in Table 5, these equations demonstrate even more clearly the economies of scale inherent in their more generalized forms and show the source of these economies to be the constant term. Similar relationships are indicated with regard to the equations for storage cost and combined cost (packinghouse plus storage cost) also presented in Table 5. From inspection of these equations, it is clear that, with a given length of season, the total season cost—under the operating conditions specified—is lower with the bulk– than with the place–pack operations.

The combined total season cost equations expressed in Table 5 as a function of total packinghouse hourly output, $V_t$, given particular values of H, are easily transformed into long–run average cost equations by dividing each by total season volume, V, equal to $V_tH$, to obtain equations of the form:

$$\text{Average cost} = \frac{a}{V_tH} + \frac{b}{H},$$

where

a and b = coefficients derived from a particular equation in Table 5

$V_t$ = total packinghouse output (1,000 pounds per hour)

and

H = hours of packinghouse operation per season.

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[1] The 250–hour packing season involves a 34–day operating period including four Sundays on which no fruit is packed but the storage equipment operates, plus three days of storage operation after conclusion of the packing season. Similarly, 400 hours of packinghouse operation involve 25 two–shift days, four Sundays, and three additional days of storage operation after the end of the packing season.

TABLE 5

Estimated Total Seasonal Cost of Pear Packinghouse and Cold Storage Operations Relation to Total Packinghouse Output Rate, $V_t$ With Selected Values of Operating Variables, Lake County, California, 1972[a]

| Type of plant | Applicable range | Packinghouse[b] | Cold storage[b] | Combined[b] |
|---|---|---|---|---|
| | | 250 hours operation per season (one 8-hour shift)[c] | | |
| Place-pack | $V_t < 180$ | $18,325 + 5,942\ V_t$ | $1,199 + 275\ V_t$ | $19,524 + 6,217\ V_t$ |
| | $V_t \geq 180$ | | $168 + 281\ V_t$ | $18,493 + 6,223\ V_t$ |
| Bulk-fill | $V_t < 180$ | $17,783 + 4,232\ V_t$ | $1,199 + 292\ V_t$ | $18,982 + 4,524\ V_t$ |
| | $V_t \geq 180$ | | $168 + 299\ V_t$ | $17,951 + 4,531\ V_t$ |
| Place-pack and bulk-fill[d] | $V_t < 180$ | $18,054 + 5,086\ V_t$ | $1,199 + 283\ V_t$ | $19,253 + 5,369\ V_t$ |
| | $V_t \geq 180$ | | $168 + 290\ V_t$ | $18,240 + 5,376\ V_t$ |
| | | 400 hours operation per season (two 8-hour shifts)[e] | | |
| Place-pack | $V_t < 180$ | $23,485 + 8,878\ V_t$ | $1,187 + 536\ V_t$ | $24,672 + 9,414\ V_t$ |
| | $V_t \geq 180$ | | $168 + 546\ V_t$ | $23,653 + 9,424\ V_t$ |
| Bulk-fill | $V_t < 180$ | $22,253 + 6,164\ V_t$ | $1,187 + 571\ V_t$ | $23,440 + 6,735\ V_t$ |
| | $V_t \geq 180$ | | $168 + 582\ V_t$ | $22,421 + 6,746\ V_t$ |
| Place-pack and bulk-fill[d] | $V_t < 180$ | $22,869 + 7,522\ V_t$ | $1,187 + 553\ V_t$ | $24,056 + 8,075\ V_t$ |
| | $V_t \geq 180$ | | $168 + 564\ V_t$ | $22,869 + 8,086\ V_t$ |

[a]With respect to both lengths of season, volume packed is specified as 65 percent of total fruit run and cannery and cull fruit as 35 percent.

[b]$V_t$ = total packinghouse output rate (1,000 pounds per hour).

[c]With 250 hours operation per season, the packinghouse is specified to operate on a single 8-hour shift or less; the cold storage to operate 37 days, 24 hours per day ($H_s$ = 888).

[d]These equations for the combination place- and bulk-fill operation are based on an equal volume of output (measured in 1,000 pounds per hour) in each type of pack.

[e]With 400 hours operation, hours of packinghouse operation per day = 16 (two 8-hour shifts); cold storage operation, 32 days per season, 24 hours per day ($H_s$ = 768).

Source: Computed.

Long–run average cost curves obtained in this way from each of the total season cost equations given in Table 5 are shown in Figure 4. The curves are asymptotic to an average cost level equal to b/H in the above equation and descend sharply only in the range of relatively small plants as would be anticipated from the derivative of the average cost equation, $dAC/dV_t = -a/V_t^2H$.

The curves in Figure 4 illustrate the previously noted economies of scale available in large– as compared with small–capacity plants and the savings possible through the use of bulk– as compared with place–pack shipping containers for fresh fruit. For example, the curves for both bulk– and place–pack operations indicate that, with 250 hours of packinghouse operation per season, the economies of scale amount to approximately $2.70 per 1,000 pounds of total fruit run in a plant of 50,000,000 pounds per season capacity as compared to one of 6,200,000 pounds capacity. Additional, although relatively small, economies of scale are available in plants of still larger capacity. Similarly, over the range of plant capacities shown, total costs per 1,000 pounds total fruit run are approximately $6.80 less with bulk– as compared with place–pack operation. Of these savings through shift from place– to bulk–fill packing, roughly $3.20 per 1,000 pounds of total fruit run comes from the difference in shipping container costs.[1] These savings would be less as the proportion of fruit packed decreases and would be greater for rates of packout larger than the 65 percent specified in this illustration.

It is evident from Figure 4 that the economies of scale, with a given type of shipping container, are not appreciably different as hours of operation per season vary over the range considered although, for practical purposes, the curve for 400 hours of packinghouse operation per season levels out at somewhat greater total season volume than with 250 hours. It also is clear that appreciable economies in plant costs should not be expected through reducing the number of plants in the District beyond the point that individual plant scale exceeds the neighborhood of 50,000,000 pounds per season. In terms of hourly rate of packinghouse operation, $V_t$, this total season volume corresponds to a packinghouse capacity rate of 200,000 pounds per hour with 250 hours of operation per season and 125,000 pounds per hour with 400 hours operation per season.

## VII. ASSEMBLY OPERATIONS

In an earlier analysis, cost relationships with two types of assembly containers and nine alternative handling methods were studied.[2] The containers considered were a lug box of approximately 42 pounds net weight capacity and a bulk bin of approximately 1,000 pounds capacity. Assembly costs with either type of container were found to vary with handling method, orchard conditions, rate of harvest, and hauling distance. Cost comparisons among the alternative methods showed the use of bins to be more economical in the long run than the use of lugs over the whole range of applicable operating conditions.

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[1] With 65 percent packed, fresh–pack volume per 1,000 pounds of fruit run is 650 pounds per hour. At 48 pounds net weight per place–packed box and a container cost of 90 cents per box, container costs amount to $12.20 per 1,000 pounds total fruit run. Similarly, with a net weight per carton of 36 pounds and a container cost of 50 cents per carton, container costs with the bulk–fill method are approximately $9.00 per 1,000 pounds total fruit run.

[2] Stollsteimer (1961).

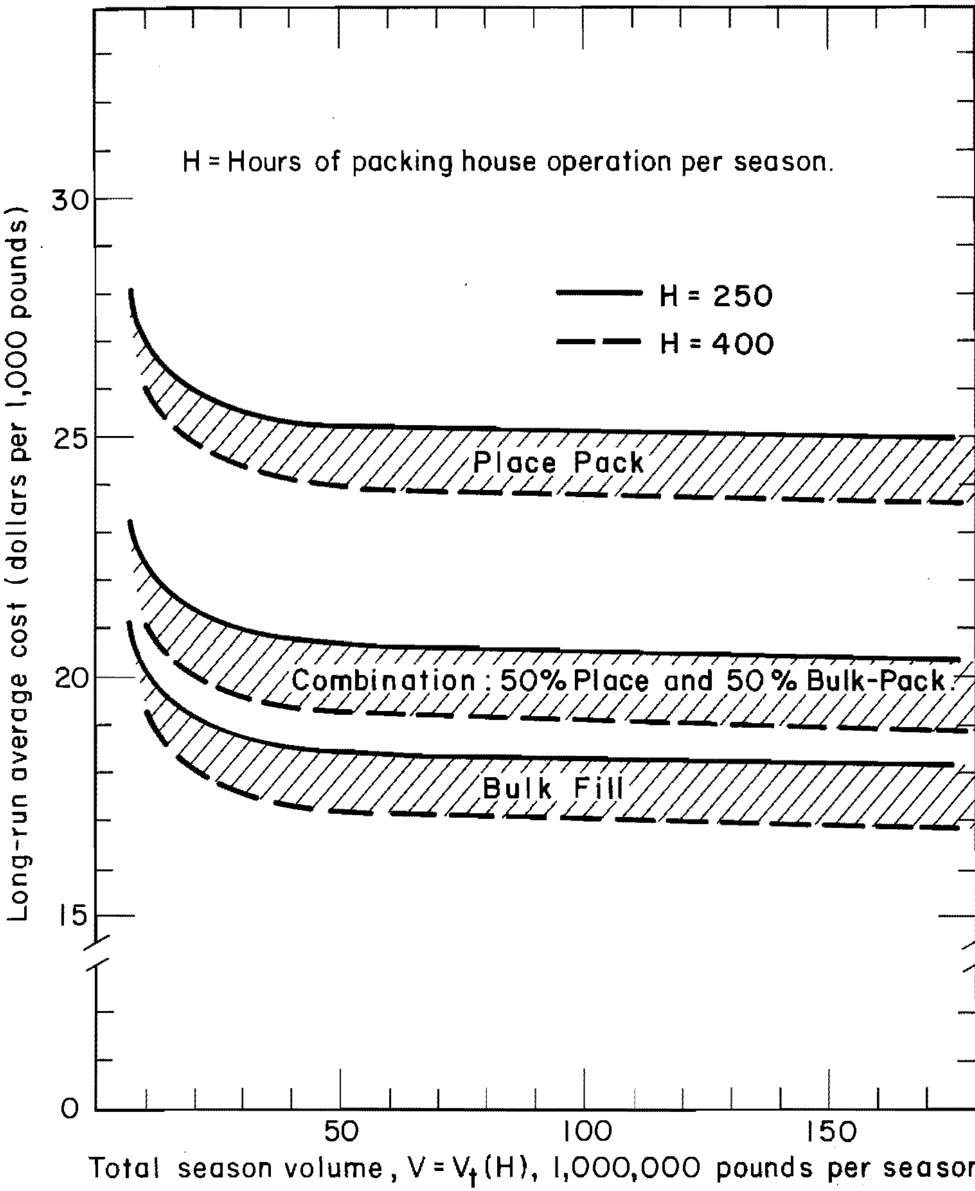


FIGURE 4. LONG–RUN AVERAGE COST CURVES FOR PEAR PACKING PLANTS (PACKINGHOUSE PLUS COLD STORAGE) UNDER SPECIFIED OPERATING CONDITIONS (65 PERCENT OF TOTAL FRUIT RUN FRESH PACKED WITH REMAINDER DIVERTED TO CANNERY AND CULL FRUIT, PACKING METHOD AND HOURS OF OPERATION PER SEASON AS INDICATED), LAKE COUNTY, CALIFORNIA, 1972

At present, bins are the only type of container used in the assembly operations, and so the following analysis considers only the selection of the least–cost, bin–handling method in relation to rate of delivery to and distance between packinghouse and orchard.

### Bin–Handling Methods and Estimating Model

In the four different bin–handling methods considered, the basic operations consist of unloading empty bins at the orchard and distributing them through the picking area, collecting and loading full bins, transporting the fruit to the packinghouse, waiting while the plant receiving crew unloads the vehicle and reloads with empty bins, and returning the empty bins to the orchard. The alternative methods, which differ in regard to the type of highway transport vehicle used and the method used in handling the bins in the orchard, are the following:

1. Truck for highway transport with tractor forklift for bin handling in the orchard (average highway speed, 20 miles per hour).
2. Trailer (low bed) for highway transport with orchard–handling operations the same as in method 1 (average highway speed, 10 miles per hour).
3. Trailer (low bed) for highway transport with tractor–mounted utility carrier, 18–inch maximum lift, for bin–handling operations at the orchard (average highway speed, 10 miles per hour).
4. Trailer (low bed) for highway transport with bins filled directly on trailer (average highway speed, 10 miles per hour).

### Costs With Alternative Assembly Methods

To facilitate cost comparisons among the alternative handling methods, a description of representative operating conditions was developed which specifies orchard conditions and layout with respect to the materials–handling operations and equipment used and time required for the receiving operations at the packinghouse.[1] Total costs (fixed plus variable) are estimated for a set of points, each of which represents total cost for a specified hauling rate, distance, and method. Labor and equipment requirements for each such point are estimated from production standards derived from elemental time requirements given for various tasks and the operating conditions specified there.[2] The physical requirements thus estimated are translated into costs through the application of appropriate cost rates.[3]

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[1] For details, see Appendix D, *infra,* pp. 134ff.

[2] Appendix Table D–1, *infra,* p. 136.

[3] The principal cost rates involved are $2.00 per hour for labor; 31 cents per hour for variable costs for tractors and trucks (including fuel, oil, and routine repairs); and equipment fixed costs as detailed in Appendix Table D–2, *infra,* p. 137.

The results of these calculations are illustrated in Table 6 with regard to operating method 1 (trucks for highway transport). The table gives—for distances of 1, 3, 5, and 10 miles—estimates of labor and equipment requirements for specified rates of delivery to the packinghouse. Similar tabulations for the remaining methods are given elsewhere.[1] These results show that, for a given crew and equipment organization, hauling capacity declines as hauling distance increases and that this effect is more pronounced with methods involving use of equipment with the slower highway speeds. These data also show how costs are affected by the type of orchard-handling method used.

In the estimation of fixed costs, annual fixed charges are computed as a fixed percentage of initial investment; and for tractors and trucks (but not for other equipment), 50 percent of this annual charge is allocated to farm uses other than hauling fruit.[2] Annual fixed costs then are reduced to fixed costs per hour of operation on the basis of a 250-hour hauling season which was indicated in interviews with growers in the Lake County District as representative of normal operating conditions.

The set of total cost points derived for each hauling method as described above is the basis for the estimation of a cost function of the form:

$$TC_a = a + b_1D + b_2Q + b_3Q_aD$$

where

$TC_a$ = total hourly assembly costs (dollars)

$D$ = one-way hauling distance (miles)

and

$Q_a$ = rate of assembly output (1,000 pounds of fruit per hour).

The cost surface equations obtained by fitting linear regressions to the calculated cost points for each method over the range of output rates and hauling distances specified are as follows:[3]

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[1] Appendix Tables D-3 and D-5, *infra*, pp. 138 and 139 and 141.

[2] Appendix Table D-2, *infra*, p. 137.

[3] The adjusted multiple $R^2$ for these equations ranges from 0.928 to 0.982. It should be emphasized, however, that the synthesized cost points do not constitute a stochastic set of data; therefore, no statistical inferences can be drawn from the usual test statistics. Nevertheless, the $R^2$ is an indicator of the closeness with which the computed equations describe the cost relationships.

TABLE 6

Crew and Equipment Requirements and Costs With Hauling Method 1--Trucks With Tractor Forklift Attachment for Orchard Handling--in Relation to Rate of Output and Length of Haul From Orchard to Plant, Lake County, California, 1972

| One-way hauling distance | Capacity output rate per hour | Crew required | Equipment required: Tractors | Trailers | Trucks | Forklift attachments | Utility carriers | Variable cost: Labor[a] | Equipment[b] | Fixed cost[c] | Total handling cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| | 1,000 pounds | men | units | | | | | dollars per hour | | | |
| 1 mile | 7.4 | 1 | 1 | d | 1 | 1 | 0 | 2.00 | .62 | 4.50 | 7.12 |
| | 9.0 | 2 | 1 | | 1 | 1 | 0 | 4.00 | .62 | 4.50 | 9.12 |
| | 10.5 | 2 | 1 | | 2 | 1 | 0 | 4.00 | .93 | 6.52 | 11.45 |
| | 17.4 | 3 | 2 | | 2 | 1 | 1 | 6.00 | 1.24 | 8.03 | 15.27 |
| | 21.1 | 3 | 2 | | 2 | 2 | 0 | 6.00 | 1.24 | 9.01 | 16.25 |
| 3 miles | 6.6 | 1 | 1 | | 1 | 1 | 0 | 2.00 | .62 | 4.50 | 7.12 |
| | 9.0 | 2 | 1 | | 1 | 1 | 0 | 4.00 | .62 | 4.50 | 9.12 |
| | 10.5 | 2 | 1 | | 2 | 1 | 0 | 4.00 | .93 | 6.52 | 11.45 |
| | 17.4 | 3 | 2 | | 2 | 1 | 1 | 6.00 | 1.24 | 8.03 | 15.27 |
| | 19.0 | 4 | 2 | | 2 | 2 | 0 | 8.00 | 1.24 | 9.01 | 18.25 |
| | 21.1 | 4 | 2 | | 3 | 2 | 0 | 8.00 | 1.55 | 11.02 | 20.57 |
| 5 miles | 5.9 | 1 | 1 | | 1 | 1 | 0 | 2.00 | .62 | 4.50 | 7.12 |
| | 9.0 | 2 | 1 | | 1 | 1 | 0 | 4.00 | .62 | 4.50 | 9.12 |
| | 10.5 | 2 | 1 | | 2 | 1 | 0 | 4.00 | .93 | 6.52 | 11.45 |
| | 13.5 | 3 | 2 | | 2 | 1 | 1 | 6.00 | 1.24 | 8.03 | 15.27 |
| | 17.4 | 4 | 2 | | 3 | 1 | 1 | 8.00 | 1.55 | 10.04 | 19.59 |
| | 21.1 | 4 | 2 | | 3 | 2 | 0 | 8.00 | 1.55 | 11.02 | 20.57 |
| 10 miles | 4.7 | 1 | 1 | | 1 | 1 | 0 | 2.00 | .62 | 4.50 | 7.12 |
| | 7.0 | 2 | 1 | | 1 | 1 | 0 | 4.00 | .62 | 4.50 | 9.12 |
| | 8.7 | 2 | 1 | | 2 | 1 | 0 | 4.00 | .93 | 6.52 | 11.45 |
| | 10.5 | 3 | 1 | | 3 | 1 | 0 | 6.00 | 1.24 | 8.53 | 15.77 |
| | 17.3 | 4 | 2 | | 3 | 1 | 1 | 8.00 | 1.55 | 10.04 | 19.59 |
| | 19.7 | 5 | 2 | | 3 | 2 | 1 | 10.00 | 1.55 | 11.02 | 22.57 |
| | 21.1 | 5 | 2 | | 4 | 2 | 0 | 10.00 | 1.86 | 13.03 | 24.89 |

a/ Based on a wage rate of $2.00 per hour.
b/ Includes 28 cents for fuel and oil and 3 cents for minor repairs per hour of truck or tractor operation.
c/ Based on annual fixed charges per equipment unit shown in Appendix Table D-2, a 250-hour operating season, and the number of units specified above.
d/ Blanks indicate this equipment not used with this method.

Sources:

Cols. 1-7: John F. Stollsteimer, "The Effect of Technical Change and Output Expansion on the Optimum Number, Size, and Location of Pear Marketing Facilities in a California Pear Producing Region" (unpublished Ph.D. dissertation, Department of Agricultural Economics, University of California, Berkeley, 1961), 250p.

Cols. 8-11: Computed.

**Hauling Method**

1. Truck with forklift:

$$TC_a = 2.14 + 0.0201\ D + 0.7146\ Q_a + 0.0348\ Q_aD \tag{40}$$

2. Trailer with forklift:

$$TC_a = 2.68 + 0.0925\ D + 0.6543\ Q_a + 0.0643\ Q_aD \tag{41}$$

3. Trailer with carrier:

$$TC_a = 1.74 + 0.2257\ D + 0.9960\ Q_a + 0.1244\ Q_aD \tag{42}$$

4. Trailer with direct loading:

$$TC_a = 1.11 + 0.1092\ D + 1.0707\ Q_a + 0.1581\ Q_aD. \tag{43}$$

The above equations can be used to compare total cost per hour, unit costs, and break–even points with respect to method, distance, and rate of delivery. By inspection, it is evident that only methods 1 and 2 are competitive with respect to cost minimization and that, for most values of $Q_a$ and D, costs are minimized with method 1. These relationships are illustrated in Figure 5 which compares unit costs with methods 1 and 2 in regard to rate of delivery at 1 and 10 miles distance.

## VIII. SPATIAL DIMENSIONS

The remaining step preliminary to determining the optimum number, size, and location of plants is to specify the spatial dimensions of the problem. These involve the geography and main road system of the District, the quantities of production by location within the District, the location of existing and potential plant sites, and a transportation cost matrix linking each product origin with each plant site.

### Geography of District

As noted in Section III, the Lake County Pear District is located in a mountainous region surrounding Clear Lake, with production occurring in a series of valleys on the southern, western, and northern sides of the upper portion of the Lake (Figure 6). The largest producing area is in Big Valley which lies to the south of the upper arm of Clear Lake; there also is a major producing area in Scotts Valley to the north and west of Big Valley; and a third area is at the northern end of the Lake in the vicinity of Upper Lake.

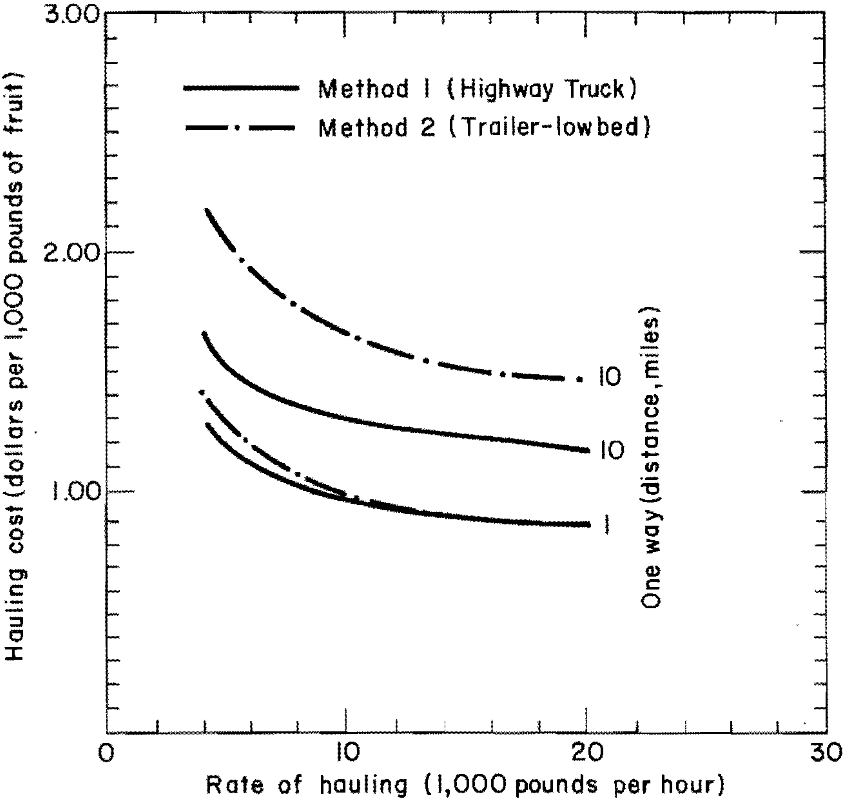


FIGURE 5. AVERAGE COST OF ORCHARD–TO–PLANT TRANSPORTATION IN RELATION TO RATE OF HAULING WITH TWO HAULING METHODS (250 HOURS OF OPERATION PER SEASON), LAKE COUNTY, CALIFORNIA, 1972

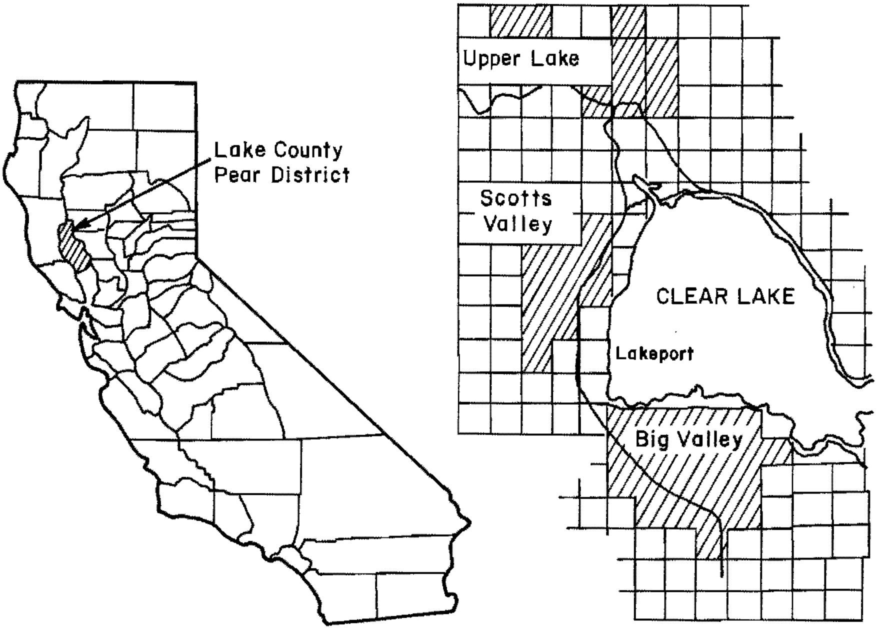


FIGURE 6. LOCATION KEY, LAKE COUNTY, CALIFORNIA, AND ITS PRINCIPAL PEAR PRODUCING AREAS, 1972

The District is traversed by state Routes 20 and 29 and is served by a network of secondary roads. There is no direct rail service to the District; but state highways provide easy truck access to major national highway systems which pass through Ukiah and Yuba City–Marysville, centers 33 and 106 miles, respectively, from the District's major town, Lakeport. At Marysville and Yuba City, there are extensive cold storage facilities and access to the national rail system.

## Location of Plant and Pear Production Facilities

For the optimizing solution that follows, it is necessary to specify the location of pear production and processing facilities.

### Present and Potential Plant Sites

At present there are 10 separately operated packinghouses in the District, the locations and letter designations of which are shown in Figure 7. Each plant in this set is considered to be a potential plant site in the optimizing solution of the following section. In addition, five other sites (G, F, H, I, and L in Figure 7) are designated at what are considered to be points well situated with respect to the principal road system and the principal geographic areas of production. It is, of course, recognized that, given the existing road system and the accessibility of any area in the District to it, a very large number of plant sites exist (theoretically, an infinite number if it is considered that any point in the continuum of space comprising the District is a potential plant site). However, the limited number of designated sites is believed sufficient for exploration of the optimizing problem.

### Pear Production Locations

In a strict sense, each orchard unit should be considered a point of origin in the assembly operations. For purposes of simplification, however, the output of all producing units within each land survey section is aggregated and, in the estimation of transportation distances and costs, considered as originating at the center of the section. Each land survey section in which pear acreage is located, with its number designation for this study, is shown in Figure 7.

## Estimates of Pear Production by Location

While a seemingly simple statistic, an estimate of present and future expected production by location within the District was perhaps the most difficult to obtain of the numerous empirical measures required for this study. However, a basis adequate for useful projections of mature bearing acreage and production within each producing survey section is believed to have been established. The procedure and results presented below are based on data concerning pear plantings and acreage in Lake County and growers' estimates of expected yield per acre when all existing trees are mature.

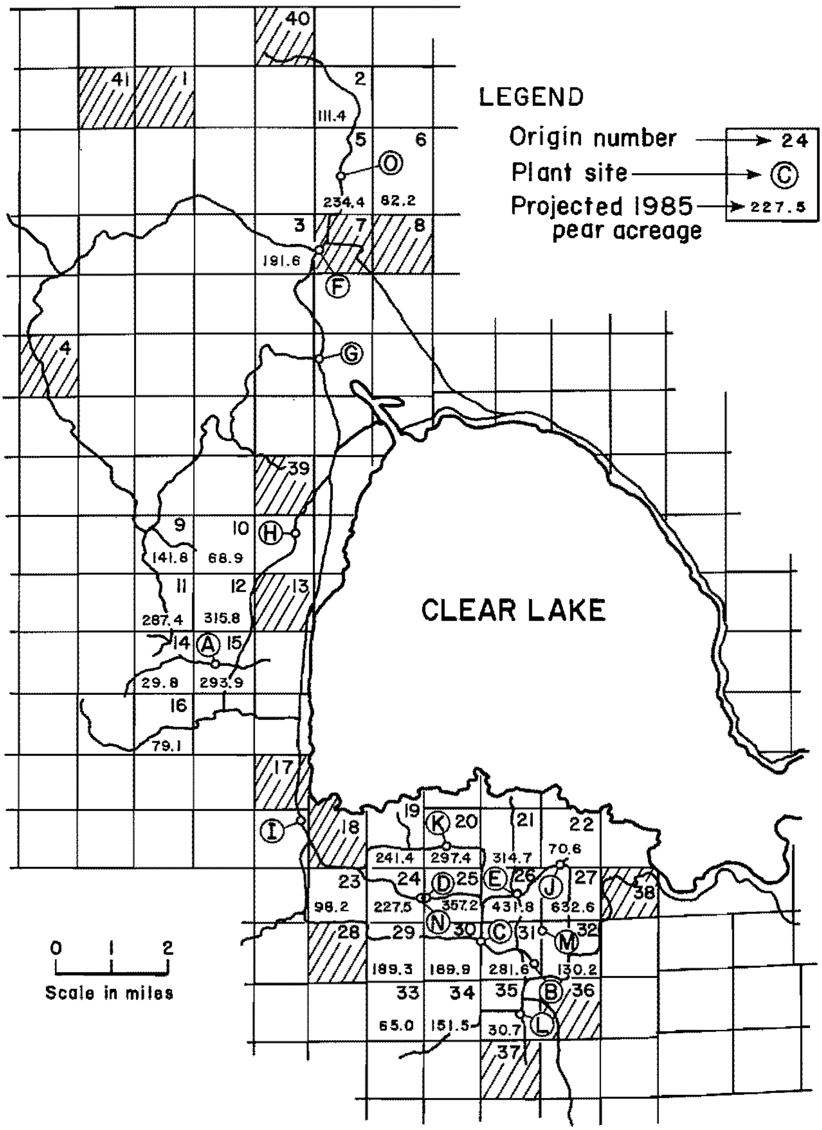


FIGURE 7. LOCATION OF PEAR PRODUCTION WITH ORIGIN NUMBER AND ACREAGE BY LAND SURVEY SECTION AND ACTUAL AND POTENTIAL PLANT LOCATIONS, LAKE COUNTY, CALIFORNIA, 1972
(Shaded sections contain pear production acreage involving less than three growers; acreage data are omitted to preserve confidentiality of acreage reporting by individual growers)

## Acreage and Locations

The basic information on pear acreage and plantings comes from unpublished data of the U. S. Crop and Livestock Reporting Service (CLRS). It has been the practice of this organization over a long period of time to make periodic census surveys of all growers in the District through which the CLRS obtains for each producer information as to location, acres in specific crops, and—with respect to pears—the date and number of trees in each planting. The most recent census was taken in the fall of 1972. During between-census periods, the acreage and planting data are continuously updated through the annual recording of the numbers of new, replacement, and interplant trees—and the spacing of such plantings—introduced by each grower. These interim data are taken from reports filed with the County Agricultural Commissioner as to nursery stock purchased for planting in the County.

The pear planting and acreage data of CLRS provide a current record of pear acreage and its location, with information as to individual plots keyed to the land survey system of range, town, and section numbers. The acreage data also include information as to tree spacing and age of trees. The loss of many trees from pear decline in the early 1960's and also a move by some growers in the direction of closer tree spacing have resulted in a large increase in plantings on existing pear acreage. In the primary CLRS data base, these plantings appear as additional acreage in order to reflect the change in potential tree-bearing surface. As a consequence, there has been, since the early 1960's, an accumulation of "double counting" of pear acreage; and this has, in part, contributed to the growth in reported pear acreage in the District from a total of 5,432 acres in 1959 to 8,566 acres in 1972.[1]

The purposes of this study require a close approximation of the actual land area in pears and its location within the District. The primary CLRS census data of 1972, fortunately, are so coded as to permit an adjustment that converts total recorded acreage to estimated acres of land in pears by land survey sections. By this means, the adjusted CLRS 1972 census data indicate acreage by land survey section to be distributed over the District as shown in Figure 7. These data indicate a total Lake County land area in pears of 5,950 acres of which 3,788 are in Big Valley, 1,233 are in Scotts Valley, and 796 are in the Upper Lake area.[2] (In the shaded sections in Figure 7, there are less than three growers; and so, to preserve confidentiality in the reporting of acreage by individual growers, acreage figures in these sections are not given. The omitted acreage, amounting to only 427 acres for the entire District, is, however, included in the above totals and in the computational matrices and analyses that follow.)

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[1] California Crop and Livestock Reporting Service (1960 through 1973).

[2] The estimated land area in pears in the District obtained by simple application of the coding rule is 6,065 acres. When the constraint is applied that adjusted acreage per farm may not exceed total acres in that unit, the District total becomes 5,950 acres which is the figure given above. Also, the 5,950-acre total includes 133 acres of pears in the vicinity of Middletown (40 miles to the south of Lakeport) which are not shown in Figure 7.

## Yield Per Acre

Pear production per acre in a given season on a particular site obviously varies in relation to many factors such as pear variety; age and spacing of trees; soil, climatic, and other environmental conditions; and cultural practices. In the Lake County District, all these variables are present except variety of fruit which is restricted to Bartletts. Ideally, there should be available a per acre yield estimate that would reflect the effect of these variables on production at each production location; but this degree of refinement is not feasible, and it is necessary to proceed on the basis of an overall District average yield. Even here, a satisfactory estimate is not readily available.

In the initial phase of this study (Stollsteimer, 1961), a District average yield per acre was computed by fitting a linear regression to average yield per equivalent acre of mature trees in which the yield data were based on time series production data over the period 1940–1959. For purposes of long-run analysis, these trends were extrapolated to the year 1970. The procedure indicated an average District yield of 16.5 tons per acre of mature trees; and this figure, applied to the estimated 1970 mature equivalent planting area of 5,103 acres, gave an estimated total projected 1970 output of 84,146 tons.

The relatively stable time trend preceding 1960 was, however, seriously disrupted by pear decline which caused heavy tree mortality such that actual production in 1969–1971 amounted to an average annual total of only 45,000 tons. The time trend projection is no longer a feasible basis for projecting future production levels in the District. One effort to cope with this problem was to seek yield projections from university pomologists and the local farm advisor; but because of insufficient exposure to postdecline cultural conditions, the necessary basis of experience was lacking.

The alternative procedure chosen was to seek information as to present yield per acre, tree spacing, and age of trees in a single year, 1971, and also the grower's estimate of expected yields when all plantings reach maturity. Statistical analysis of these data did not, however, produce useful results as to yield per acre in relation to planting density and age of tree. However, on a priori grounds and through extrapolating the results of controlled experiments on citrus, it was concluded that a lower than optimum yield might be expected with both very low and very high planting densities but that, over a broad middle range of planting densities, yield per acre would not vary greatly with changes in tree spacing.[1] If so, tree planting density, which is of increasing variability among individual plots within the District, can be ignored in the estimation of District average yield per acre.

With the above simplification, data obtained from growers through mail survey as to "expected normal yield when all trees are mature" were made the basis of estimating the anticipated District average yield per acre when all trees are mature. Data from the initial 1972 survey were augmented by a second mail survey in the spring, 1973. In the second survey, growers responding in the first survey were excluded.[2] The results indicate a mean grower yield expectation in the respective surveys of 18.2 and 14.4 tons per acre.

[1] Boswell *et al.* (1970).

[2] In the first survey, questionnaires were mailed to a nearly complete list of producers in the District (approximately 220). In the second survey a random sample was drawn from the nonrespondents in the first survey (survey total, approximately 61). Usable responses in the first survey totaled 47; in the second, 44. The standard errors of the means in the two surveys were, respectively, $S_{\bar{x}} = 0.360$ and $S_{\bar{x}} = 2.050$ tons per acre.

Statistical tests of the significance of the difference between the above estimates suggest that they are from different populations of yield estimates. However, it appears that the expected yield estimates of individual growers in a given year are an indeterminate blend of expectations directly related to the physical environment of a given location and the individual's degree of optimism at the time of survey as to future outcomes. On this basis, sampling over a period of years might be appropriate. Given these characteristics and no apparent bias in the spatial distribution of responses in the two surveys, it was decided to pool the 1971 and 1972 data despite the indications of the statistical test. The result is an estimated mature planting yield of 16.3 tons per acre.[1] (In the analytical models that follow, this estimate was rounded to 16.0 tons per acre.)

## Production Estimates

**District Total.**—With the CLRS data on acreage per land survey section and the above estimate of expected yield per acre when all plantings are at full maturity, it is a simple matter to compute expected production per land survey section as the product of acres of pear plantings times 16.0 tons per acre. Estimated annual production computed on this basis and summed over all pear producing sections indicates an expected District total annual production of approximately 95,000 tons of which 60,600 tons is attributed to the Big Valley area (including production in the vicinity of Middletown), 19,700 tons to Scotts Valley, and 12,700 tons to the Upper Lake area.

Experience with Bartlett pear plantings indicates that trees should be in full bearing by age 15 years. On this basis, one may accept the above estimate of expected production as appropriate for long-run analysis focused on a planning horizon of 1985.

Regarding the above, it is of interest that the projected per acre yield in the first (1961) phase of this study was 16.5 tons per acre (based on time trend projection) as compared with 16.3 tons per acre based on the grower survey data. Similarly, total District annual production projected to 1970 in the first phase of the study was 84,146 tons as compared with the tonnage presently projected for 1985. An additional relevant survey statistic is actual yield per acre reported by individual growers with respect to 1971 and 1972 harvests. Average actual yield in 1971, as indicated by the sample data, was 8.5 tons per acre and, in 1972, 8.7 tons per acre.[2] These figures applied to the land area in pears give an estimated District output of 50,600 tons in 1971 and 51,800 tons in 1972. The corresponding figures based on total tonnage marketed in these years are 49,200 tons in 1971 and 51,500 tons in 1972.[3]

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[1] A test of the hypothesis that the means of observations in the successive samples are equal provides a t ratio of 10.4, which suggests rejection. If the two sets of observations are nevertheless pooled on a priori grounds, the estimated confidence interval is $x = 16.3 \pm 0.7$ at the 0.05 level.

[2] The standard error of the 1971 estimated mean is 0.712; for the 1972 estimated mean, 0.850.

[3] California Tree Fruit Agreement (1973).

**Production by Land Survey Section.**—For later use the projected 1985 District production must be expressed by origin within the District. Such estimates, obtained by multiplying the adjusted CLRS acreage for each pear producing land survey section by the projected yield per acre (16.0 tons or 32,000 pounds per acre), are given in Table 7 by land survey range, town, and section number. The table also gives the origin location numbers assigned for use in the analysis as to optimum number, size, and location of plants given in the following section. The estimated production quantities given in Table 7 are expressed in units of 1,000 pounds rather than the industry reporting units of tons in order to make the production data compatible with the volume variables of the preceding cost analyses. Note also that Table 7 does not include estimated production from 133 acres, nearly all in the vicinity of Middletown, that are thought to be too remote from the Lakeport District to be an appropriate factor in the optimizing solution.[1] Total acreage involved in the optimizing solution then is 5,817; and projected 1985 total output of the included areas is 186,130,000 pounds (93,065 tons as compared with the projected total annual District output of 95,000 tons). Acreage and production data specific to sections with less than three growers are omitted to preserve confidentiality in the acreage reporting of individual growers. However, these omitted quantities are included in the column totals and in subsequent analyses. The total acreage (and corresponding production) not shown for individual sections in Table 7 amounts to only 315 acres or 10 million pounds of fruit.

The above findings suggest that continuing annual plantings of pear trees in the District since 1960 have mainly involved replacement of trees suffering from serious decline (or the interplanting of existing trees to accomplish a change in cultural practice) with little change in total land area in pears. Also, comparison of total District production in 1971 and 1972, determined from pear marketing information and similar estimates based on grower survey data, supports acceptance of the adjusted CLRS acreage data as a reasonable approximation of current pear acreage in the District. Finally, given little present evidence of growers' intentions to expand pear acreage and the fact that minor additions to pear acreage would not appreciably affect total District output in 1985, the projected District output of 95,000 tons as of that date is believed to provide an acceptable output figure for long–run analysis. The principal reservation to this conclusion is the possibility of serious reversals in present efforts to control the effects of pear decline.

## Assembly Transportation Costs

The final preliminary step toward the optimizing solution is the construction of a transportation cost matrix that specifies the cost of moving a given quantity of pears from each production location to each prospective plant site. This requires the development of a transport mileage matrix and the application to it of transportation cost relationships presented in Section VII.

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[1] Had the omitted acreage been included in the optimizing solutions that follow, the locational "pull" toward Big Valley would have been increased slightly. However, the overall outcome would not have been significantly different.

TABLE 7

Estimated Production of Pears When All Existing Plantings Are Mature, by Land Survey Section
Lake County, California (Projected Production, 1985)

| Land survey section | | | Origin number | Adjusted land area in pears | Estimated production[a] |
|---|---|---|---|---|---|
| Town (N) | Range (W) | Section | | acres | 1,000 pounds |
| 16 | 10 | 34 | 1 | b | |
| 16 | 9 | 31 | 2 | 111.39 | 3,564.48 |
| 15 | 10 | 12 | 3 | 191.59 | 6,130.88 |
| 15 | 10 | 20 | 4 | | |
| 15 | 9 | 6 | 5 | 234.44 | 7,502.08 |
| 15 | 9 | 5 | 6 | 82.19 | 2,630.08 |
| 15 | 9 | 7 | 7 | | |
| 15 | 9 | 8 | 8 | | |
| 14 | 10 | 3 | 9 | 141.79 | 4,537.28 |
| 14 | 10 | 2 | 10 | 68.90 | 2,204.80 |
| 14 | 10 | 10 | 11 | 287.39 | 9,196.48 |
| 14 | 10 | 11 | 12 | 315.79 | 10,105.28 |
| 14 | 10 | 12 | 13 | | |
| 14 | 10 | 15 | 14 | | |
| 14 | 10 | 14 | 15 | 293.89 | 9,404.48 |
| 14 | 10 | 22 | 16 | 78.09 | 2,498.88 |
| 14 | 10 | 25 | 17 | | |
| 14 | 9 | 31 | 18 | | |
| 14 | 9 | 32 | 19 | 241.39 | 7,724.48 |
| 14 | 9 | 33 | 20 | 297.39 | 9,516.48 |
| 14 | 9 | 34 | 21 | 314.74 | 10,071.68 |
| 14 | 9 | 35 | 22 | 79.65 | 2,548.80 |
| 13 | 9 | 6 | 23 | 98.29 | 3,145.28 |
| 13 | 9 | 5 | 24 | 227.49 | 7,279.68 |
| 13 | 9 | 4 | 25 | 357.24 | 11,431.68 |
| 13 | 9 | 3 | 26 | 431.79 | 13,817.28 |
| 13 | 9 | 2 | 27 | 632.64 | 20,244.48 |
| 13 | 9 | 7 | 28 | | |
| 13 | 9 | 8 | 29 | 189.19 | 6,054.08 |
| 13 | 9 | 9 | 30 | 189.94 | 6,078.08 |
| 13 | 9 | 10 | 31 | 281.74 | 9,015.68 |
| 13 | 9 | 11 | 32 | 130.19 | 4,166.08 |
| 13 | 9 | 17 | 33 | 65.00 | 2,080.00 |
| 13 | 9 | 16 | 34 | 151.49 | 4,847.68 |
| 13 | 9 | 15 | 35 | 30.69 | 982.08 |
| 13 | 9 | 14 | 36 | | |
| 13 | 9 | 22 | 37 | | |
| 13 | 9 | 1 | 38 | | |
| 15 | 10 | 36 | 39 | | |
| 16 | 10 | 25 | 40 | | |
| 16 | 10 | 33 | 41 | | |

[a]Adjusted acres times average grower's expected yield--16.0 tons per acre--when all trees are mature; excludes from production 133 acres mainly in the vicinity of Middletown.

[b]Blanks indicate that sections for which acreage and production data are not shown contain fewer than three growers; hence, data specific to these sections are omitted to preserve confidentiality in data collection. The acreage omitted amounts to only 315.54 acres in relation to the District total of 5,817 acres. The data omitted here are included in subsequent analyses.

Sources: Unpublished data of the California Crop and Livestock Reporting Service; see, also, Figure 7 for spatial distribution of pear acreage.

In constructing this transportation matrix, it was recognized that two existing plants (at sites D and N) were in such close proximity as to be indistinguishable in the computation of assembly distances and so not distinguishable as separate sites in the programming solution. These two sites are, therefore, combined in Table 8 and in all subsequent calculations; only 14 plant locations are considered.

### Assembly Distances

Hauling distances between each origin—that is, each pear producing land survey section and each potential plant site—are given in Table 8. These distances were computed by scaling from a map similar to Figure 7 the airline distance between the center of a particular producing section and a given plant site. Road mileages were estimated from such airline distances by multiplying airline distance by $\sqrt{2}$; that is,

$$RD = AD\sqrt{2} \tag{44}$$

where RD equals estimated road mileage and AD equals measured airline mileage. The mileage adjustment involved in the application of equation (44) is considered to provide a good approximation of actual road distances since the basic secondary road system in most of the District follows the grid pattern of the land survey system. Equation (44) in effect treats airline distance as the hypotenuse of a 45–degree triangle and equates the sum of the sides of that triangle to a measure of road distance.[1]

### Assembly Cost Matrix

Assembly costs per 1,000 pounds of fruit transported between each origin and each potential plant site are shown in Table 9. The costs are derived from the hauling distances given in Table 8 and the assembly cost equations developed in Section VII. For any particular origin, hauling distance to a given plant site is fixed; but rate of hauling per hour is a variable depending on the annual production at a given origin and hours of hauling operation per season. Data for dealing explicitly with this problem are not available, and so a simplified treatment was used. This involved selection of the capacity rate of operation per hour for one assembly crew as the hauling rate at which the transportation cost matrix would be computed. Examination of Table 6 indicates that, for the least–cost assembly methods, this crew capacity rate is approximately 10,000 pounds per hour; and this is the rate on which Table 9 is based. In given producing sections, seasonal hauling requirements would be satisfied by varying the number of assembly crews used. In low–volume sections in which average rate of hauling per hour with the selected operating season of 250 hours results in a lower average rate than 10,000 pounds per hour, possible operating adjustments include working fewer hours per season, shifting to lower capacity but higher cost methods, or using custom haulers. It is believed, however, that such adjustments would not have a major effect on the optimizing solution, and so the hauling rate of 10,000 pounds per day is uniformly applied in the construction of Table 9.

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[1] While the assumptions involved in this adjustment do not hold for all origins and plant sites, road mileages thus estimated were close approximations of estimated road miles obtained by scaling the road distances along apparent best lines of travel between randomly selected plant sites and origins.

TABLE 8

Estimated Road Mileage Between Origins and Potential Pear Packing Plant Sites
Lake County, California, 1972[a]

| Origin number | Potential plant sites | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D & N | E | F | G | H | I | J | K | L | M | O |
| | miles | | | | | | | | | | | | | |
| 1 | 13.40 | 22.60 | 21.44 | 19.93 | 20.64 | 4.27 | 6.67 | 11.03 | 17.82 | 20.36 | 19.09 | 23.47 | 19.69 | 4.48 |
| 2 | 13.82 | 21.78 | 20.90 | 19.51 | 19.88 | 3.70 | 6.45 | 11.03 | 17.82 | 19.46 | 18.53 | 22.62 | 20.09 | 4.62 |
| 3 | 10.01 | 18.72 | 17.68 | 16.17 | 16.83 | 0.85 | 3.02 | 7.35 | 14.28 | 16.60 | 15.30 | 19.37 | 4.48 | 4.75 |
| 4 | 8.60 | 19.03 | 17.56 | 15.84 | 17.22 | 7.09 | 6.48 | 7.49 | 13.01 | 16.39 | 15.41 | 19.32 | 11.95 | 10.86 |
| 5 | 12.27 | 20.05 | 19.09 | 17.75 | 18.10 | 1.95 | 4.67 | 9.16 | 16.09 | 17.67 | 16.77 | 20.93 | 18.46 | 2.72 |
| 6 | 12.69 | 19.74 | 18.95 | 17.75 | 17.96 | 2.77 | 5.06 | 9.47 | 16.20 | 17.39 | 16.63 | 20.79 | 18.33 | 1.63 |
| 7 | 10.72 | 18.33 | 17.39 | 15.92 | 16.41 | 0.71 | 2.97 | 7.44 | 14.28 | 16.12 | 14.99 | 19.23 | 16.83 | 1.49 |
| 8 | 11.14 | 18.04 | 17.19 | 15.92 | 16.20 | 2.01 | 3.62 | 7.92 | 14.45 | 15.70 | 14.90 | 18.95 | 16.43 | 2.17 |
| 9 | 3.24 | 13.72 | 12.30 | 10.61 | 12.01 | 8.14 | 5.80 | 3.11 | 7.64 | 12.34 | 10.10 | 14.28 | 12.16 | 9.50 |
| 10 | 3.10 | 12.81 | 11.56 | 9.90 | 11.03 | 7.61 | 5.03 | 1.70 | 7.21 | 11.31 | 9.27 | 13.57 | 12.22 | 9.10 |
| 11 | 1.97 | 12.73 | 11.28 | 9.47 | 11.03 | 9.33 | 6.93 | 3.39 | 6.50 | 11.45 | 9.19 | 13.23 | 11.95 | 10.86 |
| 12 | 1.55 | 12.10 | 10.41 | 8.63 | 10.10 | 8.91 | 6.31 | 2.15 | 5.91 | 10.41 | 8.17 | 12.44 | 10.86 | 10.32 |
| 13 | 2.26 | 10.89 | 9.58 | 7.92 | 9.08 | 8.57 | 5.91 | 1.41 | 5.63 | 9.36 | 7.32 | 11.59 | 10.05 | 10.05 |
| 14 | 1.41 | 12.02 | 10.21 | 8.48 | 10.18 | 10.74 | 8.26 | 4.21 | 5.23 | 10.77 | 8.06 | 12.30 | 11.00 | 12.22 |
| 15 | 0.50 | 10.72 | 9.28 | 7.49 | 9.02 | 10.24 | 7.69 | 3.25 | 4.55 | 9.53 | 7.15 | 11.26 | 10.05 | 11.68 |
| 16 | 1.83 | 10.81 | 9.33 | 7.55 | 9.36 | 12.10 | 9.56 | 5.29 | 4.21 | 10.18 | 7.61 | 11.26 | 10.32 | 13.44 |
| 17 | 3.38 | 7.66 | 6.19 | 4.38 | 6.31 | 13.09 | 10.44 | 5.88 | 1.22 | 7.07 | 4.38 | 8.14 | 7.33 | 14.26 |
| 18 | 5.22 | 5.78 | 4.23 | 2.39 | 4.38 | 14.28 | 11.59 | 7.10 | 0.99 | 5.23 | 2.60 | 6.22 | 5.43 | 15.61 |
| 19 | 6.06 | 4.65 | 3.24 | 1.55 | 3.11 | 14.39 | 11.74 | 7.49 | 2.26 | 3.93 | 1.27 | 5.29 | 4.21 | 15.61 |
| 20 | 7.19 | 3.81 | 2.68 | 1.69 | 2.01 | 14.62 | 12.02 | 8.09 | 3.67 | 2.54 | 0.53 | 4.67 | 2.85 | 16.02 |
| 21 | 8.46 | 2.82 | 2.68 | 2.68 | 1.44 | 15.04 | 12.53 | 8.85 | 5.15 | 1.22 | 1.73 | 4.38 | 2.44 | 2.04 |
| 22 | 9.73 | 3.38 | 3.38 | 3.95 | 2.12 | 15.55 | 13.24 | 9.81 | 6.59 | 0.99 | 3.53 | 4.38 | 1.63 | 16.83 |
| 23 | 5.64 | 5.16 | 3.67 | 1.97 | 4.21 | 15.70 | 13.01 | 8.48 | 1.78 | 5.23 | 2.83 | 5.34 | 5.16 | 16.97 |
| 24 | 7.05 | 3.81 | 2.34 | 0.85 | 2.77 | 15.72 | 13.06 | 8.80 | 2.68 | 3.90 | 1.98 | 4.24 | 3.67 | 16.97 |
| 25 | 8.04 | 2.76 | 1.41 | 0.85 | 1.41 | 15.89 | 13.32 | 9.19 | 3.93 | 2.54 | 1.07 | 3.39 | 2.31 | 17.38 |
| 26 | 9.02 | 2.00 | 1.55 | 2.23 | 0.28 | 16.15 | 13.72 | 9.89 | 5.23 | 1.16 | 1.84 | 3.11 | 0.81 | 17.65 |
| 27 | 10.15 | 2.22 | 2.68 | 3.81 | 1.56 | 16.74 | 14.39 | 10.74 | 6.76 | 0.98 | 3.25 | 3.28 | 3.67 | 18.06 |
| 28 | 7.61 | 4.79 | 3.38 | 2.40 | 4.38 | 17.11 | 14.42 | 9.89 | 3.11 | 5.66 | 3.59 | 4.67 | 5.29 | 18.33 |
| 29 | 8.18 | 3.38 | 1.97 | 1.55 | 3.08 | 17.17 | 14.48 | 10.12 | 3.73 | 4.24 | 2.68 | 3.39 | 3.80 | 18.46 |
| 30 | 9.02 | 2.03 | 0.99 | 1.55 | 1.89 | 17.34 | 14.70 | 10.61 | 4.67 | 3.14 | 2.40 | 2.26 | 2.44 | 18.74 |
| 31 | 10.01 | 0.81 | 0.99 | 2.68 | 1.36 | 17.70 | 15.10 | 11.11 | 5.80 | 2.23 | 2.88 | 1.61 | 1.09 | 19.01 |
| 32 | 11.00 | 1.13 | 2.40 | 3.89 | 1.95 | 18.07 | 15.55 | 11.91 | 7.21 | 1.95 | 3.82 | 2.12 | 1.09 | 19.28 |
| 33 | 9.59 | 3.53 | 2.54 | 2.82 | 3.82 | 18.47 | 15.98 | 11.51 | 4.89 | 5.14 | 4.10 | 3.08 | 2.99 | 19.82 |
| 34 | 10.15 | 2.26 | 1.72 | 2.82 | 3.08 | 18.89 | 16.12 | 11.87 | 5.62 | 4.24 | 3.82 | 1.69 | 3.26 | 20.09 |
| 35 | 11.00 | 0.99 | 1.75 | 3.53 | 2.69 | 18.97 | 16.49 | 12.41 | 6.65 | 3.54 | 4.10 | 0.31 | 2.44 | 20.36 |
| 36 | 11.99 | 1.27 | 2.82 | 4.51 | 3.08 | 19.43 | 16.94 | 13.09 | 7.72 | 3.39 | 4.81 | 1.16 | 2.44 | 20.64 |
| 37 | 12.13 | 2.28 | 3.10 | 4.71 | 4.10 | 20.50 | 17.93 | 13.71 | 7.66 | 4.95 | 8.31 | 1.41 | 3.67 | 21.72 |
| 38 | 11.40 | 2.99 | 3.80 | 4.62 | 2.72 | 17.11 | 14.66 | 11.67 | 8.15 | 1.77 | 4.62 | 3.80 | 4.75 | 18.46 |
| 39 | 4.48 | 13.17 | 12.22 | 10.59 | 11.40 | 5.70 | 3.12 | 1.50 | 8.15 | 11.40 | 9.64 | 14.12 | 12.22 | 7.33 |
| 40 | 14.79 | 22.94 | 22.13 | 20.21 | 21.18 | 5.16 | 7.60 | 11.95 | 18.60 | 20.91 | 21.04 | 24.16 | 21.72 | 3.53 |
| 41 | 13.44 | 23.08 | 22.13 | 20.36 | 21.45 | 6.52 | 8.01 | 11.40 | 17.79 | 21.31 | 19.55 | 24.16 | 22.13 | 5.70 |

[a] From airline distances by means of the following relationship: $RD = AD\sqrt{2}$, where RD = road distance (miles) and AD = air distance (miles). Existing plant sites D and N are combined in column 5 because their close proximity precludes differentiation of transport distances.

Source: Computed.

TABLE 9

Estimated Cost Per 1,000 Pounds of Fruit Transported Between Pear Producing Origins and Potential Plant Sites, Lake County, California, 1972

| Origin number | Potential plant site | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D & N | E | F | G | H | I | J | K | L | M | O |
| | dollars | | | | | | | | | | | | | |
| 1 | 1.42 | 1.76 | 1.71 | 1.66 | 1.68 | 1.08 | 1.17 | 1.33 | 1.58 | 1.67 | 1.63 | 1.79 | 1.65 | 1.09 |
| 2 | 1.43 | 1.73 | 1.69 | 1.64 | 1.66 | 1.06 | 1.16 | 1.33 | 1.58 | 1.64 | 1.61 | 1.76 | 1.67 | 1.66 |
| 3 | 1.29 | 1.61 | 1.57 | 1.52 | 1.54 | 0.95 | 1.03 | 1.19 | 1.45 | 1.53 | 1.49 | 1.64 | 1.09 | 1.10 |
| 4 | 1.24 | 1.62 | 1.57 | 1.51 | 1.56 | 1.18 | 1.16 | 1.20 | 1.40 | 1.53 | 1.49 | 1.63 | 1.36 | 1.32 |
| 5 | 1.38 | 1.66 | 1.63 | 1.58 | 1.59 | 1.00 | 1.10 | 1.26 | 1.52 | 1.57 | 1.54 | 1.69 | 1.60 | 0.93 |
| 6 | 1.39 | 1.65 | 1.62 | 1.58 | 1.58 | 1.03 | 1.11 | 1.27 | 1.52 | 1.56 | 1.54 | 1.69 | 1.60 | 0.98 |
| 7 | 1.32 | 1.60 | 1.56 | 1.51 | 1.53 | 0.95 | 1.03 | 1.20 | 1.45 | 1.52 | 1.48 | 1.63 | 1.54 | 0.98 |
| 8 | 1.33 | 1.59 | 1.56 | 1.51 | 1.52 | 1.00 | 1.06 | 1.22 | 1.46 | 1.50 | 1.47 | 1.62 | 1.63 | 1.01 |
| 9 | 1.04 | 1.43 | 1.38 | 1.31 | 1.37 | 1.22 | 1.14 | 1.04 | 1.20 | 1.38 | 1.30 | 1.45 | 1.40 | 1.28 |
| 10 | 1.04 | 1.40 | 1.35 | 1.29 | 1.33 | 1.20 | 1.11 | 0.99 | 1.19 | 1.34 | 1.26 | 1.42 | 1.38 | 1.26 |
| 11 | 1.00 | 1.39 | 1.34 | 1.27 | 1.33 | 1.27 | 1.18 | 1.05 | 1.16 | 1.35 | 1.26 | 1.41 | 1.37 | 1.33 |
| 12 | 0.98 | 1.37 | 1.31 | 1.24 | 1.30 | 1.25 | 1.16 | 1.00 | 1.14 | 1.31 | 1.22 | 1.38 | 1.33 | 1.31 |
| 13 | 1.01 | 1.32 | 1.28 | 1.22 | 1.26 | 1.24 | 1.14 | 0.98 | 1.13 | 1.27 | 1.19 | 1.35 | 1.30 | 1.30 |
| 14 | 0.98 | 1.37 | 1.30 | 1.24 | 1.30 | 1.32 | 1.23 | 1.08 | 1.12 | 1.32 | 1.22 | 1.38 | 1.33 | 1.38 |
| 15 | 0.94 | 1.32 | 1.27 | 1.20 | 1.26 | 1.30 | 1.21 | 1.04 | 1.09 | 1.27 | 1.19 | 1.34 | 1.30 | 1.36 |
| 16 | 0.99 | 1.32 | 1.27 | 1.20 | 1.27 | 1.37 | 1.28 | 1.12 | 1.08 | 1.30 | 1.20 | 1.34 | 1.31 | 1.42 |
| 17 | 1.05 | 1.21 | 1.15 | 1.08 | 1.16 | 1.41 | 1.31 | 1.14 | 0.97 | 1.18 | 1.08 | 1.22 | 1.20 | 1.45 |
| 18 | 1.12 | 1.14 | 1.08 | 1.01 | 1.08 | 1.45 | 1.35 | 1.18 | 0.96 | 1.12 | 1.02 | 1.15 | 1.13 | 1.50 |
| 19 | 1.15 | 1.09 | 1.04 | 0.98 | 1.04 | 1.45 | 1.36 | 1.20 | 1.01 | 1.07 | 0.97 | 1.12 | 1.08 | 1.50 |
| 20 | 1.19 | 1.06 | 1.02 | 0.99 | 1.00 | 1.46 | 1.37 | 1.22 | 1.06 | 1.02 | 0.94 | 1.10 | 1.03 | 1.52 |
| 21 | 1.24 | 1.03 | 1.02 | 1.02 | 0.98 | 1.48 | 1.38 | 1.25 | 1.11 | 0.97 | 0.99 | 1.08 | 1.02 | 1.00 |
| 22 | 1.28 | 1.05 | 1.05 | 1.07 | 1.00 | 1.50 | 1.41 | 1.28 | 1.17 | 0.96 | 1.05 | 1.08 | 0.98 | 1.54 |
| 23 | 1.13 | 1.11 | 1.06 | 1.00 | 1.08 | 1.50 | 1.40 | 1.24 | 0.99 | 1.12 | 1.03 | 1.12 | 1.12 | 1.55 |
| 24 | 1.18 | 1.06 | 1.01 | 0.95 | 1.03 | 1.50 | 1.40 | 1.25 | 1.02 | 1.07 | 1.00 | 1.08 | 1.06 | 1.55 |
| 25 | 1.22 | 1.03 | 0.98 | 0.95 | 0.98 | 1.51 | 1.41 | 1.26 | 1.07 | 1.02 | 0.96 | 1.05 | 1.01 | 1.57 |
| 26 | 1.26 | 1.00 | 0.98 | 1.01 | 0.93 | 1.52 | 1.43 | 1.29 | 1.12 | 0.97 | 0.99 | 1.04 | 0.96 | 1.58 |
| 27 | 1.30 | 1.01 | 1.02 | 1.06 | 0.98 | 1.54 | 1.45 | 1.32 | 1.17 | 0.96 | 1.04 | 1.04 | 1.06 | 1.59 |
| 28 | 1.20 | 1.10 | 1.05 | 1.01 | 1.08 | 1.55 | 1.45 | 1.29 | 1.04 | 1.13 | 1.06 | 1.10 | 1.12 | 1.60 |
| 29 | 1.22 | 1.05 | 1.00 | 0.98 | 1.04 | 1.56 | 1.46 | 1.30 | 1.06 | 1.08 | 1.02 | 1.05 | 1.07 | 1.61 |
| 30 | 1.26 | 1.00 | 0.96 | 0.98 | 0.99 | 1.56 | 1.46 | 1.31 | 1.10 | 1.04 | 1.01 | 1.01 | 1.02 | 1.62 |
| 31 | 1.29 | 0.95 | 0.96 | 1.02 | 0.97 | 1.58 | 1.48 | 1.33 | 1.14 | 1.01 | 1.03 | 0.98 | 0.97 | 1.63 |
| 32 | 1.33 | 0.97 | 1.01 | 1.07 | 1.00 | 1.59 | 1.50 | 1.36 | 1.19 | 1.00 | 1.06 | 1.00 | 0.97 | 1.64 |
| 33 | 1.28 | 1.05 | 1.02 | 1.03 | 1.06 | 1.60 | 1.51 | 1.35 | 1.10 | 1.11 | 1.07 | 1.04 | 1.04 | 1.66 |
| 34 | 1.30 | 1.01 | 0.99 | 1.03 | 1.04 | 1.62 | 1.52 | 1.36 | 1.13 | 1.08 | 1.06 | 0.99 | 1.05 | 1.67 |
| 35 | 1.33 | 0.96 | 0.99 | 1.05 | 1.02 | 1.62 | 1.53 | 1.38 | 1.17 | 1.05 | 1.07 | 0.94 | 1.02 | 1.68 |
| 36 | 1.36 | 0.97 | 1.03 | 1.09 | 1.04 | 1.64 | 1.55 | 1.41 | 1.21 | 1.05 | 1.10 | 0.97 | 1.01 | 1.68 |
| 37 | 1.37 | 1.01 | 1.04 | 1.10 | 1.07 | 1.68 | 1.58 | 1.43 | 1.21 | 1.11 | 1.23 | 0.98 | 1.06 | 1.73 |
| 38 | 1.34 | 1.03 | 1.06 | 1.09 | 1.02 | 1.55 | 1.46 | 1.35 | 1.22 | 0.99 | 1.09 | 1.06 | 1.10 | 1.61 |
| 39 | 1.09 | 1.41 | 1.37 | 1.31 | 1.34 | 1.13 | 1.04 | 0.98 | 1.22 | 1.34 | 1.28 | 1.44 | 1.38 | 1.20 |
| 40 | 1.47 | 1.77 | 1.74 | 1.67 | 1.70 | 1.11 | 1.20 | 1.36 | 1.61 | 1.69 | 1.70 | 1.81 | 1.73 | 1.06 |
| 41 | 1.42 | 1.77 | 1.74 | 1.67 | 1.71 | 1.16 | 1.22 | 1.34 | 1.58 | 1.71 | 1.64 | 1.81 | 1.74 | 1.14 |

Sources: Computed from mileage matrix, Table 8, and unit costs shown in Figure 5.

The use of the assembly cost equations to compute transport costs per 1,000 pounds of fruit hauled may be illustrated by computing the cost of shipping from origin 2 to plant site A. Table 8 gives the hauling distance between these points as 13.82 miles; and examination of equations (40) to (43) indicates that, at this distance and with a hauling rate of 10,000 pounds per hour, the least–cost technique is method 1. From equation (40), the unit hauling cost for the values of $Q_a$ and D specified then is established as \$1.43 per 1,000 pounds transported. The remaining entries in Table 9 were computed in a similar manner.

## IX. OPTIMUM NUMBER, SIZE, AND LOCATION OF PLANTS

From the preceding sections, estimates may be drawn of packinghouse, cold storage, and assembly cost relationships needed to determine the optimum (cost–minimizing) number, size, and location of plants in a given pear producing district. These cost relationships are applied here to the projected 1985 quantities and locations of production as developed for the Lake County District in Section VIII. This application initially is to the specific operating conditions that underlie the long–run total and average cost relationships presented in Table 5 and Figure 4 and in regard to a plant that packs only bulk–filled cartons.[1] The effect of variation in certain key variables is also examined.

For the conditions specified, Table 5 presents the long–run relationship between total plant cost (packinghouse and cold storage) and hourly rate of output in equations of the following form:

$$TPC = a + b\,V_t \tag{45}$$

where

TPC = total season plant cost (dollars)

a and b = constants

and

$V_t$ = total packinghouse output (1,000 pounds per hour).

Equation (45) is linear with respect to $V_t$. As previously shown, this means that, given uniform factor prices at the various plant locations, total long–run plant costs will vary with the number of plants provided to process a given regional output by an amount equal to the constant term. The above relationship applies here since the assumption of equal factor prices at various plant sites is warranted in this analysis. Packinghouse wage rates, for example, are determined for the entire area through a single collective bargaining agreement; and, given the close proximity of the potential plant sites and the absence of any evidence of pecuniary economies of scale in the prices of variable inputs, delivered factor prices for the other major inputs should be essentially equal throughout the District.

[1] Operating conditions specified: of total fruit run, packed fruit is 65 percent; cannery and cull fruit is 35 percent. With 250 hours of packinghouse operation per season, cold storage operates 37 days and $H_s$ = 888 hours. With 400 hours of packinghouse operation per season, cold storage operates 32 days and $H_s$ = 768.

## Application of the Model

With economies of scale indicated in the plant cost relationships (equation 45) and the assumption of uniform factor prices at all plant sites, the appropriate cost-minimization procedure is that described as case III in Section II. Restatement of that procedure in the context of the conditions specified above involves the following.

### Total Cost Function

The total cost function to be minimized may be written as follows:

$$TC = \sum_{j=1}^{J} P_j X_j \mid L_J + \sum_{i=1}^{I} \sum_{j=1}^{J} c_{ij} X_{ij} \mid L_J \tag{46}$$

where

$TC$ = total season assembly and plant costs (dollars)

$\sum_{i=1}^{41} X_{ij} = X_j$ = volume of fruit handled at plant j in 1,000 pounds

$\sum_{j=1}^{J} X_{ij} = X_i$ = volume of pears produced in the *i*th section of the county; i = 1 ... 41 in 1,000 pounds (these data are specified in Table 7)

$\sum_{i=1}^{41} \sum_{j=1}^{J} X_{ij} = X$ = 186,130,000 pounds (total projected pear output is specified in Table 7)

$P_j$ = unit processing cost in plant j, to be estimated by means of equation (45)

$C_{ij}$ = cost of shipping 1,000 pounds of pears from origin i to plant j located at site L (these costs are specified in Table 9)

and

$L_j$ = one combination of locations among the $14_J$ possible combinations of locations (the 14 potential plant sites considered in this analysis are specified in Figure 7).

**Minimum Transfer Costs**

The 41 x 14 transportation cost matrix, $C_{ij}$, applicable in solving for the set of plant locations which minimize transfer costs, given a specified number of plants, is shown in Table 9. A 41 x 1 vector, $X_i$, whose entries, $x_i$, represent the volume of pears to be assembled from each origin, may be formed from the data in Table 7. Given these two sets of data, a transfer cost function, $\overline{TTC} \mid J$, minimized with respect to plant locations, may be specified by means of the procedure outlined in Section II with respect to case III. The solution may involve any number of plant sites from 1 to 14.

The numerical operations involved in determining this function from the data contained in Tables 7 and 9 were carried out on an IBM 1130 computer. The operations performed by the computer may be briefly summarized as follows.

1. Given the 41 x 14 transportation cost matrix, $C_{ij}$, form the submatrices, $C^*_{ij}$, obtained by considering all possible combinations of the columns of this matrix; that is, form $\Sigma_{J=1}^{14}\ 14_J$ submatrices. These submatrices represent transportation cost matrices for all possible combinations of plant locations. For J = 1, these submatrices will consist of 14, 41 x 1 matrices; for J = 2, 66, 41 x 2 matrices; etc.

2. Given these submatrices, each is scanned by rows; and the minimum element in each row is selected and used to form $14_J$ (41 x 1) vectors for each value of J. These minimum row values indicate the minimum transfer cost for the production of a given origin and a particular set of locations for J plants.

3. Each of the vectors formed in (2) is multiplied by $(X_i)'$, a 1 x 41 vector of fruit quantities. These vector multiplications yield total transfer costs with J plants in each of the $\Sigma_{J=1}^{14}\ 14_J$ possible plant locations. The minimum of these values is selected for each J, and the set of plant locations (columns of $C_{ij}$) associated with this minimum value is specified. The level of the minimized total transfer costs is also specified in this process.

**Optimum Plant Locations**

The optimal locational pattern with a range of 1 to 14 possible plant sites is specified in Table 10. For example, with only one plant, assembly costs are minimized with a plant located at site K; with two plants, the optimum locations are sites E and H; and so on.[1] This empirically determined pattern corresponds rather closely to an a priori,

[1] To test the stability of site K as the optimum: note that with only one plant the sites with the next lowest single–plant assembly costs are either D or E. Total assembly costs with a single plant located at either D or E were less than 1 percent greater than total assembly costs with a single plant at K which suggests that site K provides a close approximation of the true minimum.

TABLE 10

Optimum Plant Locations, Plant Sizes, and Minimum Assembly Costs in Relation to Number of Plants (With 250 or 400 Hours of Operation Per Season), Lake County, California, 1972

| Number of plants | Optimum set of locations[a] | Minimized total assembly costs | Total receipts by individual plants | Required hourly plant capacity: 250-hour season | Required hourly plant capacity: 400-hour season |
|---|---|---|---|---|---|
| | | dollars | 1,000 pounds | | |
| 1 | K | 209,915 | 186,122 | 744.5 | 465.3 |
| 2 | E | 193,196 | 121,211 | 484.8 | 303.0 |
| | H | | 64,911 | 259.6 | 162.3 |
| 3 | A | 184,959 | 39,438 | 157.8 | 98.6 |
| | E | | 121,211 | 484.8 | 303.0 |
| | F | | 25,473 | 101.9 | 63.7 |
| 4 | A | 182,643 | 39,438 | 157.8 | 98.6 |
| | E | | 58,810 | 235.2 | 147.0 |
| | F | | 62,401 | 249.6 | 156.0 |
| | D | | 25,473 | 101.9 | 63.7 |
| 5 | A | 181,928 | 39,438 | 157.8 | 98.6 |
| | D | | 58,810 | 235.2 | 147.0 |
| | E | | 62,401 | 249.6 | 156.0 |
| | F | | 13,767 | 55.1 | 34.4 |
| | O | | 11,706 | 46.8 | 29.3 |
| 6 | ADEFJO | 181,290 | b | | |
| 7 | ADEFJKO | 180,737 | | | |
| 8 | ABDEFJKO | 180,239 | | | |
| 9 | ABCDEFJKO | 180,000 | | | |
| 10 | ABCDEFJHKO | 179,846 | | | |
| 11 | ABCDEFJHIKO | 179,801 | | | |
| 12 | ABCDEFJHIKLO | 179,778 | | | |
| 13 | ABCDEFGJHIKLO | 179,777 | | | |
| 14 | ABCDEFGJHIKLMO | 179,777 | | | |

[a]Plant sites as designated in Figure 7.

[b]Blanks reflect omission of individual plant data to avoid needless expansion of table. Also, the maximum number of sites shown is only 14 due to the consolidation of locations D and N in the programming analysis.

Source: Computed.

theoretical locational pattern. Thus, if there is to be only one plant, transfer costs presumably would be minimized by locating it in or near the most intensively planted region of the County, with some compensation for the locational pulls of the two other production regions, a condition that site K satisfies.

With two plants, sites E and H minimize assembly costs, again a result consistent with theory. However, the exact plant locations would be more difficult to predict than in the previous case. Site E, the center of a very dense production area, would be a likely site; but sites F, G, H, and A would all be strong contenders as a site for the second plant.

With three plants, the optimum combination sites A, E, and F quite logically place one plant in each of the three centers of production in the District.

### Minimized Assembly Costs

Assembly costs, minimized with respect to plant locations with varying numbers of plants, are also shown in Table 10 and in Figure 8. These costs decline as the number of plants increases but only in minor degree as plant numbers increase beyond three—a pattern which provides a plant in each of the major producing regions of the District.

### Plant Size

The assignment of a given number of plants to a specified set of locations, along with minimization of assembly costs, implies a given size of plant for each location. For example, with two plant sites, locations E and H are shown in Table 10 to yield minimum transfer costs, while reference to Table 9 shows that this involves assigning production at origins 1 through 17 to plant site H and the production at sites 18 through 41 to plant site E. With total plant receipts at site E of 121,211,000 pounds and at site H of 64,911,000 pounds and a 250–hour season, hourly plant capacity at site E must be 484,800 pounds and at site H, 259,600 pounds.[1] With a 400–hour season, the required packing capacities would be 303,000 pounds per hour at site E and 162,300 pounds at site H.

### Total District Plant Costs

Proceeding still under the conditions applicable to case III of Section II (linear cost functions, with economies of scale and constant factor prices throughout the District) and using the appropriate cost functions for bulk–fill packing given in Table 5, total District season plant costs are given by the following equations:

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[1] These plant capacities assume that receipts at a given plant arrive uniformly over the season, thus permitting the plant to operate at the capacity output rate during each hour of operation. The problem of determining optimum plant capacity, given nonuniform arrival rates, is treated in Section X.

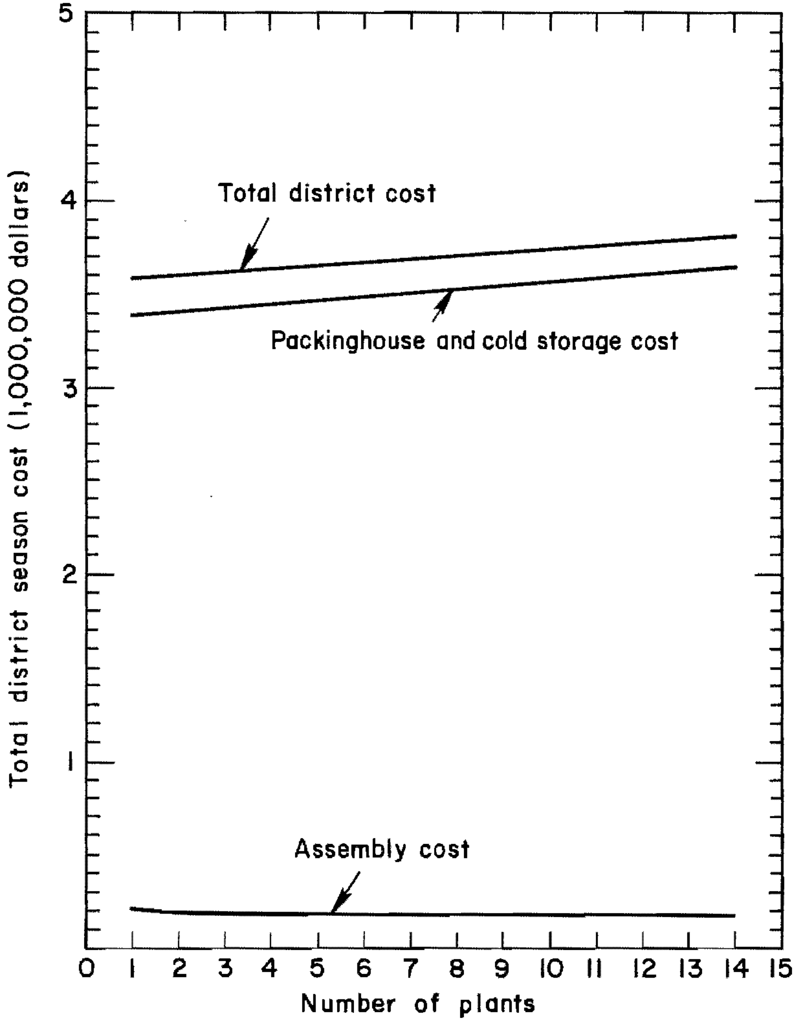


**FIGURE 8. TOTAL DISTRICT SEASON COST OF ASSEMBLY, PACKING, PRECOOLING AND STORING, AND LOADING PEARS IN RELATION TO NUMBER OF PLANTS (FRESH PACK—IN BULK-FILLED CARTONS—65 PERCENT OF TOTAL FRUIT RUN, 250 HOURS OF PACKINGHOUSE OPERATION PER SEASON), LAKE COUNTY, CALIFORNIA, 1972**

*With H = 250*

$$V_t < 180: \quad TDPC = (18{,}982)N_a + 4{,}524 \sum_j^{N_a} V_{tj} \tag{46a}$$

$$V_t \geqslant 180: \quad TDPC = (17{,}951)\,N_b + 4{,}531 \sum_j^{N_b} V_{tj} \tag{46b}$$

*With H = 400*

$$V_t < 90: \quad TDPC = (23{,}440)\,N_c + 6{,}735 \sum_j^{N_c} V_{tj} \tag{46c}$$

$$V_t \geqslant 90: \quad TDPC = (22{,}421)\,N_d + 6{,}746 \sum_j^{N_d} V_{tj} \tag{46d}$$

where

TDPC = total District season plant cost (dollars)

$N_a$ and $N_b$ = set of plants within a specified range of values of $V_t$ with H = 250

$N_c$ and $N_d$ = set of plants within a specified range of values of $V_t$ with H = 400

$V_{tj}$ = capacity rate of plant operation in 1,000 pounds per hour at location j

and

H = hours of packinghouse operation per season.

Substituting in equation (46) the respective values of N, H, and the plant capacities given in Table 10 with each set in the sequence of increasing plant numbers, the estimates of total District season plant cost are as given in Table 11. These estimates are, it is recalled, specific to plants which operate at a uniform capacity rate per hour for the length of season indicated and with 65 percent of the total fruit run processed for fresh sale in the bulk–fill carton pack and the remainder diverted to cannery and cull fruit.

TABLE 11

Estimated Long-Run Total District Season Costs in the Assembly, Packing, Storing, and Loading of Pears in Relation to Number of Plants and Length of Packing Season (Bulk-Fill Carton Pack; Packed Volume = 65 Percent of Total Fruit Run)
Lake County, California, 1972

| Number of plants | Total District season costs in relation to operating hours, H | | | | |
|---|---|---|---|---|---|
| | | Plant costs | | Combined costs | |
| | Assembly costs | With H = 250 | With H = 400 | With H = 250 | With H = 400 |
| | 1 | 2 | 3 | 4 | 5 |
| | 1,000 dollars | | | | |
| 1 | 209.9 | 3,391.2 | 3,161.4 | 3,601.1 | 3,371.3 |
| 2 | 193.2 | 3,409.2 | 3,183.8 | 3,602.4 | 3,377.0 |
| 3 | 183.6 | 3,427.4 | 3,206.5 | 3,611.0 | 3,390.1 |
| 4 | 182.6 | 3,445.3 | 3,229.0 | 3,627.9 | 3,411.6 |
| 5 | 181.9 | 3,464.3 | 3,252.4 | 3,646.2 | 3,434.3 |
| 6 | 181.3 | 3,482.6 | 3,275.1 | 3,663.9 | 3,456.4 |
| 7 | 180.7 | 3,501.0 | 3,298.1 | 3,681.7 | 3,478.8 |
| 8 | 180.2 | 3,519.9 | 3,321.4 | 3,700.1 | 3,501.6 |
| 9 | 180.0 | 3,538.9 | 3,344.9 | 3,718.9 | 3,524.9 |
| 10 | 179.8 | 3,557.9 | 3,368.2 | 3,737.7 | 3,548.0 |
| 11 | 179.8 | 3,576.9 | 3,391.7 | 3,756.7 | 3,571.5 |
| 12 | 179.8 | 3,595.8 | 3,415.1 | 3,775.6 | 3,594.9 |
| 13 | 179.8 | 3,614.8 | 3,438.5 | 3,794.6 | 3,618.3 |
| 14 | 179.8 | 3,633.8 | 3,462.0 | 3,813.6 | 3,641.8 |

Sources:

Col. 1: Table 10.

Cols. 2 and 3: Computed.

Cols. 4 and 5: Assembly plus plant costs.

### Total District Assembly and Plant Costs

The optimizing solution is completed by adding to the estimated total plant costs associated with each set of plants shown in Table 11 the estimated minimum total assembly costs developed in Table 10. The results in relation to operating seasons of 250 and 400 hours are given in Table 11 and shown graphically for the 250–hour season in Figure 8.

## Optimal and Suboptimal Solutions

Given the criterion of cost minimization, total District season costs, as given in Table 11, define the optimum solution. The cost effects of deviations from it are considered below under two categories of circumstances: (1) the purely long–run situation with no prior commitments of resources and (2) an intermediate situation in which certain institutional constraints are considered.

### Long–Run Solution

With no prior resource commitments, the long–run optimum solution is shown in Table 11 to involve a single plant in which the packinghouse operates 400 hours per season and in which total District season cost is estimated as $3,371,300. (From Table 10, the location may be identified as site K and the plant capacity as 465,300 pounds per hour.) A solution involving two plants would be almost equally as good as for a single plant. With as many as five plants, total District season cost is no more than $63,000 per season (2 percent) greater than with one plant; and with a plant at each of the 14 sites considered, total District season costs are $270,500 (8 percent) more than with one plant. Similar relationships are evident in the results based on 250 hours of packinghouse operation per season.

The results in Table 11 show that a substantial departure from the optimum number of plants can occur without serious diseconomies measured in terms of long–run total District season costs.

### Constrained Solutions

For the District to adjust to the optimum solution indicated above would require both drastic consolidation of existing facilities and a complete shift to bulk–fill packing and 2–shift operation of the packinghouse. Whether this degree of change would be feasible would depend on the magnitude of potential savings in relation to certain commonly recognized "frictions" in such adjustment processes. For example, one might encounter concern as to possible revenue loss to existing firms if consolidation were to eliminate established brand identities. Similarly, caution in regard to change might arise from loyalties to existing management and operating personnel or in regard to unevaluated variance in the cost estimates and in the projected quantities and locations of production that underlie the optimum solution. Market resistance to further shifts to the bulk–fill carton pack might be substantial, and a work force amenable to a night–shift operation might not be available or––if available––might be employable only at a premium wage rate for the night shift.

Constraints such as the above are largely institutional in nature and may prevail against indications of potential cost savings through change. Data for complete assessment of the effect of such constraints are not available in this study, but additional information bearing on the question can be developed in terms of the "opportunity cost" of not achieving the optimum adjustment. The results of this kind of analysis are summarized in Table 12 which compares optimized total District long–run costs with estimated costs under several intermediate (suboptimal) solutions.

The reference model in Table 12 is alternative 1, the long–run optimum solution defined in Table 11 and involving a single plant operating 400 hours per season with the entire fresh output packed in the bulk–fill carton. Relative to this base, Table 12 indicates that a single–plant solution––but with only 250 hours of packinghouse operation per season (alternative 2)––involves an opportunity cost of $229,800 per season. The opportunity cost in this case represents the foregone "savings" if the adjustment to 400 hours of operation per season is not made. Similarly, alternative 3, which is the same as the optimum solution (alternative 1) except that half of the packout is in the standard box rather than the carton and thus conforms approximately to present practice in the District, involves an opportunity cost of $601,000 per season.

To operate at more sites than the single–plant optimum solution involves negligible to small diseconomies. Thus, with alternative 4 (three plants, one in each principal producing area), the estimated opportunity cost is only $22,500 per season; with alternative 5 (five plants, utilizing the present locations of the five cooperatives), the opportunity cost is only $72,600 per season. Alternative 6 (utilizing all existing plants) involves an estimated opportunity cost of $179,000 per season. Alternative 7 corresponds to the present organization of packing and shipping operations in the District and involves an estimated opportunity cost of $967,400. This represents potential gains from reducing the number of plants from 10 to 1, a change from 1– to 2–shift operation, and a shift from 50 to 100 percent carton pack. However, whether an opportunity cost of this magnitude actually exists is subject to qualifications of the type previously mentioned.

## Sensitivity Tests

The stability of the results in Tables 11 and 12 can be partially tested by assigning alternative values to certain key variables. The results of a limited assessment of this nature are given in Table 13. The reference model, as in Table 12, is alternative 1 (long–run optimum: one plant, 100 percent carton pack, 400–hours–per–season operation, and no wage differential for the second shift).

Overall, the results in Table 13 suggest no major disturbance of the relationships indicated in Table 12. In alternative 1(a), for example, an increase in total District season cost of approximately $155,000 is shown to result from the introduction of the 5 percent second–shift wage differential. However, this alternative remains lower in total season cost compared with single–shift operation (250 hours per season) although the difference is small––only 2.1 percent. The assumption that some existing facilities would continue in use, even though some consolidation were to occur––alternatives 4(a), 5(a), and 6(a)––involves an "intermediate" run and a reduction in annual fixed charges by

TABLE 12

Comparison of Optimal and Suboptimal Solutions in the Organization of Assembly, Packing, Shipping, and Loading Operations for Pears Lake County, California, 1972

| Number | Solution alternative[a] | Total District cost | Potential annual savings relative to alternative 1 |
|---|---|---|---|
| | | 1,000 dollars | |
| 1 | Long-run optimum solution (1 plant with 400 hours of operation per season) | 3,371.3 | -- |
| 2 | Long-run optimum solution (1 plant but with 250 hours of operation per season) | 3,601.1 | 229.8 |
| 3 | Solution 1 but with only 50 percent of fresh pack in cartons, remainder in standard box | 3,972.3 | 601.0 |
| 4 | 3 plants operating 400 hours per season (utilizing 1 existing plant in each principal producing area--sites A, E, and O) | 3,393.8 | 22.5 |
| 5 | 5 plants operating 400 hours per season (utilizing all existing cooperatives--sites A, B, C, D, and E) | 3,443.9 | 72.6 |
| 6 | 10 plants operating 400 hours per season (utilizing all existing plants--sites A, B, C, D, E, J, K, M, and O) | 3,550.3 | 179.0 |
| 7 | 10 plants operating 250 hours per season (utilizing all existing plants--sites A, B, C, D, E, J, K, M, and O) but with only 50 percent of fresh pack in cartons; remainder in standard box | 4,338.7 | 967.4 |

[a]Except where otherwise specified, all alternative solutions assume that all fruit is packed in bulk-filled cartons, with 65 percent of total fruit run processed as fresh pack and 35 percent as canner and culls, 400 hours of operation per season.

Source: Table 11, or calculated.

TABLE 13

Sensitivity Tests With Respect to Optimal Solutions in the Organization of Assembly, Packing, Shipping, and Loading Operations for Pears Lake County, California, 1972

| Number | Solution alternative | Total District cost | |
|---|---|---|---|
| | | H = 250 | H = 400 |
| | | 1 | 2 |
| | | 1,000 dollars | |
| 1 | Long-run optimum (1 plant with 400 hours of operation per season, no shift wage differential) | a | 3,371.3 |
| 1(a) | Long-run optimum (1 plant with 400 hours of operation per season, with wage differential for the second shift) | 3,601.1 | 3,526.3 |
| 4(a) | 3 plants but with plant costs adjusted to reflect continued use of an existing facility in each principal producing area--sites A, B-C, and O[b] | 3,424.5 | 3,335.0 |
| 5(a) | 5 plants but with plant costs adjusted to reflect continued use of 5 largest existing plants--sites A, B, C, D, and E[b] | 3,505.1 | 3,419.6 |
| 6(a) | 10 plants (all existing plants) but with plant costs adjusted to reflect continued use of all existing facilities--sites A, B, C, D, E, J, K, M, and O[b] | 3,535.1 | 3,372.8 |
| 7 | Long-run optimum but with season production volume at alternative levels[c] | | |
| | V = 75 percent of projected 1985 season volume (cost minimum with 1 plant) | 2,705.4 | 2,605.0 |
| | V = 90 percent of projected 1985 season volume (cost minimum with 1 plant) | 3,242.6 | 3,144.5 |
| | V = 110 percent of projected 1985 season volume (cost minimum with 1 plant) | 3,958.6 | 3,802.9 |
| 8 | Cost minimum with alternative proportions of packed fruit (one plant) | | |
| | Fresh pack = 50 percent of total fruit run | 3,042.7 | 2,809.3 |
| | Fresh pack = 85 percent of total fruit run | 4,230.2 | 3,992.8 |

[a] A single plant with 250 hours of operation per season involves more than minimum total District cost and so is omitted from this reference line.

[b] Alternative 4(a) is the same as alternative 4 in Table 12 except that sites A and B are substituted for the long-run, cost-minimizing site E. Alternatives 5(a) and 6(a) correspond with alternatives 5 and 6, respectively, in Table 11. In all three alternatives, packing and cold storage cost equations are adjusted to reflect continued use of existing facilities as indicated. This adjustment involves reducing long-run annual fixed charges by an amount equal to depreciation charged in computing long-run costs on a fraction of total plant capacity equal to that of existing facilities continued in operation.

[c] V = District total season volume.

Sources:

Col. 1: Figure for number 1(a) from Table 11; all other figures calculated.

Col. 2: Figure for number 1 from Table 11; all other figures calculated using procedures and data on which Table 11 is based and with second-shift wage rates 5 percent higher than day shift.

amounts depending on the extent to which new plant investment is reduced.[1] Comparison of results for these alternatives shows that, for a given number of plants, a 400–hour operating season continues to yield lower District total season cost than a 250–hour season even after introduction of the second–shift wage differential.[2] These differences are, however, small––2.7 percent in alternative 4(a) and 2.5 and 4.8 percent, respectively, in alternatives 5(a) and 6(a).

With either operating season specified, the continuation of major existing facilities in each of the three producing areas of the District would yield intermediate–run total District season costs lower than full long–run costs that assume no continuing use of existing facilities. The optimum solution under this specification would be alternative 4(a) although, again, alternatives 5(a) and 6(a) appear to be very close competitors.

In alternative 7, the optimum solution is tested for the effect of season total District volume different from that projected for 1985 but continuing in all other respects the operating conditions specified in Table 11.[3] As before, 2–shift, 400–hours–per–season operation with a single plant is shown in Table 13 to be the long–run optimum. While not specifically tested as to stability in relation to the types of variations specified in alternatives 1(a) through 6(a) in Table 13, similar results could be expected.

With alternative 8, the cost–minimizing solution––with different proportions of fruit packed––again involves a single plant operated 2 shifts per day, although the range in total District season cost with one, two, or three plants is small (in the neighborhood of 1 percent). The level of total cost with these alternative proportions of packed fruit, as compared with 65 percent packout, reflects primarily differences in the costs of packing materials and packing labor as the proportion packed of a given total volume changes.

Among all the alternatives considered in Tables 12 and 13, a compelling case for replacement of existing facilities and concentration of operations in a single new and optimally located plant is not apparent in terms of lower total District season cost. An appreciable cost saving through shift to a 100 percent carton pack from the present practice of a 50–50 split of the packout in cartons and standard boxes could be realized, although further consideration would be required of such factors as possible effect on revenues from fresh sales and on cold storage operations.

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[1] Model 4(a) assumes the continuation of existing plants at sites A, B, C, and 0. It differs for model 4 of Table 12 in the replacement of site E with sites A and B which are in close proximity to each other and assumed to be operable as a single plant. This permits utilizing in the intermediate–run solution the two large existing plants at sites A and B rather than the small existing plant at site E. This modification more closely approximates a practical intermediate–run solution.

[2] In this adjustment of the long–run plant cost functions, the estimated annual fixed costs of buildings and equipment are adjusted downward by the amount of the depreciation charge. The remaining elements of the annual fixed–cost calculations––interest on the investment, fixed repairs, insurance, and taxes––remain as costs of continuing the existing facilities in service.

[3] The two lower percentages of projected annual volume specified in alternative 7 may also be used to represent total District season costs if part of the projected District output is shipped directly to the cannery without passing through the packinghouse. However, a decision to bypass the packinghouse with direct shipment to cannery would involve consideration of revenue as well as cost effects since the direct shipments of field–run fruit would mean the diversion of some fruit from the fresh market. Prices and returns from both markets would then be affected.

# X. OPTIMAL FACILITIES WITH SEASONAL AND RANDOM VARIATIONS IN DEMAND FOR PRODUCTIVE CAPACITY

In the preceding analysis the demand for productive capacity—defined as the rate per time period at which material is received for processing—is held constant with respect to rate both within and among seasons. This is a useful simplification in considering the effect of changes in certain key variables. However, it is also of interest to consider the substantial variation in daily receipts that occurs within a given season and, among seasons, in the total annual District output and to consider as well the effects of these variations on total season cost. These aspects are dealt with to a limited degree in this section.

The seasonal plant receipts pattern in a given year is characterized by relatively low daily delivery rates during the opening days of the harvest season, a gradual increase as the season progresses, and a peak near the middle of the season with receipts remaining high for a week or more. A gradual decline follows this peak period with receipts finally falling to zero. Variations among seasons are in large degree random and reflect climatic and cultural conditions peculiar to a given season.[1]

The question as to what type and quantity of facilities will minimize costs, given varying demands for facilities over time in a given season, is basically the question considered in "waiting line" or "queuing" problems. It arises when, during the course of operating a process, there are either (1) periods in which the demand for facilities is excessive, resulting in the development of a waiting line or queue, or (2) the demand for facilities is so slight relative to those available that idle facility time results. Variations among seasons in total annual output are studied in terms of defining the plant capacity that will minimize total District cost over a planning horizon.

## Effects of Within–Season Variation in Daily Receipts

In pear packing operations the daily demand for processing capacity may be met by providing facilities that (1) have sufficient capacity to process all receipts within the normal operating period, (2) have lower hourly processing capacity than in (1) but with hours of operation per day adjusted to varying daily demands, or (3) are designed for processing a portion of each day's receipts and storing the remainder, thus transferring part of the daily demand for processing capacity to a later point in time.

Each of these alternative methods is to a degree a substitute for the other, and each is likely to involve different costs. If all fruit is to be processed on the day of arrival within the normal operating period, daily plant capacity must be equal to expected peak daily receipts. Relatively large investments in processing facilities are then required, and idle processing capacity will exist on all days when receipts are below the expected maximum level. Additional hours of daily operation to meet peak demands for processing capacity permit reduction in the required capital outlay for processing facilities but also involve additional operating costs if premium wage rates must be paid during other than normal hours of operation. Use of storage operations to transfer demands for productive capacity from peak demand to relatively slack periods permits reduction in the processing facilities provided but requires additional storage facilities. Determination of the optimum

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[1] In exceptional circumstances—for example, the "pear decline" that struck the Lake County District in the early 1960's—a sustained depression in output may occur. However, with the reduced level of productivity, plant receipts would still vary within and among seasons.

set of facilities and operating rule regarding overtime and storage operations involves obtaining a balance between the costs associated with the use of each of these alternative methods of meeting varying daily demands for productive capacity.

Additional variables, which the firm must consider in planning facilities, consist of the likelihood of being unable to meet the demand for productive capacity during some portion of the operating season and the related cost. This cost would be the penalty the firm would pay in terms of lost revenue or additional expense as a result of being unable to handle a given day's receipts in the facilities provided.

The problem considered in this section is that of determining the combination of processing and storage capacities and the operating rule with respect to the storage of field–run fruit and overtime operations which minimizes the expected combined processing, storage, and penalty costs associated with handling a given total volume of fruit arriving at the plant in a seasonal pattern subject to random variations.

## The Model

Algebraically, this problem may be stated as follows:

$$\begin{aligned}\min_{V,S,k} TPC\,(V, S, k \mid \pi, \overline{q}) = \min_{V,S,k} \Big[A_V &+ B_{1V} H_{st}\,(V, S, k \mid \pi, \overline{q}) \\ &+ B_{2V} H_{ot}(V, S, k \mid \pi, \overline{q}) + TSSC\,(V, S, k \mid \pi, \overline{q}) \\ &+ M \sum_{j=1}^{J} X_{mj}\,(V, S, k \mid \pi, \overline{q})\Big]. \end{aligned} \quad (47)$$

In this system the random variable $\pi$ equals the pattern in which fruit arrives at the plant. The following variables are functions of $\pi$ and thus, also, random variables:

TPC = total season plant cost (dollars)

TSSC = total season storage cost (dollars)

$H_{st}$ = hours of packinghouse operation per season at straight–time wage rates, as a function of V, S, k, given $\pi$ and $\overline{q}$

$H_{ot}$ = hours of packinghouse operation per season at overtime wage rates, as a function of V, S, k, given $\pi$ and $\overline{q}$

$H_s$ = hours of storage operation per season = f $(H_{st}, H_{ot})$

and

$\sum_{j=1}^{J} X_{mj}$ = total tons of penalty fruit per season where penalty fruit on any given day, $X_{mj}$, is defined as that part of total receipts which cannot be accommodated by the facilities specified by $V_t$ and S and operating rule k, given $\pi$ and $\overline{q}$.

The parameters of the system are assumed to be:

$\bar{q}$ = mean daily arrival rate = V/J where V is defined as the total season volume of fruit received and J is the total number of days in the receiving season

$A_v$ = fixed cost per season for a packinghouse with hourly capacity $V_t$ (dollars)

$B_{1v}$ = operating cost per hour of straight–time operation for a packinghouse with hourly capacity $V_t$ (dollars per hour)

$B_{2v}$ = operating cost per hour of overtime operation for a packinghouse with hourly capacity $V_t$ (dollars per hour)

$f\ (S, H_s)$ = function which specifies total season storage cost, TSSC, for any given set of values for S = a two–parameter vector [R, A] where R is refrigeration capacity of the storage measured in tons of refrigeration, A is storage floor space, and $H_s$ is hours of storage operation per season, $f\ (H_{st}, H_{ot}, V, k)$, given $\pi$ and $\bar{q}$

and

M = cost per ton of penalty fruit, that is, the loss in revenue or additional costs incurred as a result of not having sufficient facilities to handle a ton of fruit at the time it is delivered to the plant in a normal manner (dollars).

The controllable variables of the system are:

$V_t$ = hourly packinghouse output (1,000 pounds per hour)

S = storage capacity defined in terms of the vector [R, A] which specifies refrigeration capacity in tons of refrigeration and storage space in 1,000 square feet of floor space

and

k = operating rule which specifies company policy with respect to overtime operations and storage of field–run fruit.

**Expected Costs**

In the above function, total season cost is a random variable because of the random elements in $\pi$, the receipts pattern. The minimum expected total season cost function, E (TPC), may be written as follows:

$$\min_{V,S,k} E\,[TPC\,(V, S, k \mid \pi, \bar{q})] = \min_{V,S,k} \Big\{ A_v + B_{1v}\, E\,[H_{st}\,(V, S, k) \mid \pi, \bar{q}\,] + B_{2v}\, E\,[H_{ot}\,(V, S, k) \mid \pi, \bar{q}\,] + E\,[TSSC\,(V, S, k) \mid \pi, \bar{q}\,] + M \sum_{j=1}^{J} E\,[X_{mj}\,(V, S, k) \mid \pi, \bar{q}\,] \Big\}. \tag{48}$$

The expected cost–minimizing combination of plant and storage facilities with any given operating rule, k, is specified by simultaneously solving the following differential equations for $V_t$ and S:

$$\frac{\partial E\,(TPC)}{\partial V_t} = \frac{\partial A_v}{\partial V_t} + \frac{\partial B_{1v}}{\partial V_t} E\,(H_{st}) + \frac{\partial E\,(H_{st})}{\partial V_t} B_{1v} + \frac{\partial B_{2v}}{\partial V_t} E\,(H_{ot}) + \frac{\partial E\,(H_{ot})}{\partial V_t} B_{2v} + \frac{\partial E\,(TSSC)}{\partial V_t} + \frac{\partial \sum_{j=1}^{J} E\,(X_{mn})}{\partial V_t} M = 0. \tag{49}$$

$$\frac{\partial E\,(TPC)}{\partial S} = \frac{\partial E\,(TSSC)}{\partial S} + \frac{\partial \sum_{j=1}^{J} E\,(X_{mn})}{\partial S} M = 0. \tag{50}$$

The last equation may be rewritten in terms of the vector [R, A] as the following two equations:

$$\frac{\partial E\,(TPC)}{\partial R} = \frac{\partial E\,(TSSC)}{\partial R} + \frac{\partial \sum_{j=1}^{J} E\,(X_{mj})}{\partial R} M = 0. \tag{51}$$

$$\frac{\partial E\,(TPC)}{\partial A} = \frac{\partial E\,(TSSC)}{\partial A} + \frac{\partial \sum_{j=1}^{J} E\,(X_{mj})}{\partial A} M = 0. \tag{52}$$

Equations (51) and (52) state that a necessary condition for minimizing expected costs is that storage capacity be substituted for penalty fruit to a point where the increase in storage costs associated with an increase in either refrigeration capacity or storage space is equal to the accompanying decline in penalty costs.

In the empiric solution of equations (49) and (50), expected costs can be approximated by substituting P, the expected receipts distribution, for $\pi$ on both sides of equation (48). Given the functional relationships implied by these equations, it is possible to solve directly for the combination of plant and storage capacities which minimizes the expected cost of handling any specified volume of fruit arriving at the plant in the seasonal pattern specified by P. However, these interrelationships are quite complex; and their specification is especially difficult because of their dependence upon daily receipts which, in turn, are a function of time. A direct analytical solution was, therefore, abandoned in favor of a simulation algorithm which can be used to solve for (1) expected costs with various values of plant capacity, storage capacity, and operating rule, given fixed values for the receipts pattern and mean daily arrival rate; or (2) realized costs, given fixed values for plant capacity, storage capacity, and operating rule and variations in the receipts pattern with a fixed daily arrival rate or simultaneous variations in the receipts pattern and arrival rate.

## Specification of Variables

In the problem considered here, the variables involved are specified as follows:

1. The total volume of fruit received during the season, $\Sigma_{j=1}^{J} q_j$, where $q_j$ is the quantity of fruit received on day j.

2. The seasonal pattern in which this total quantity of fruit arrives at the plant, that is, specification of the vector P.

3. Packinghouse capacity $V_t$, storage capacity in terms of refrigeration capacity R, and storage space A.

4. Policy (operating rule k) with respect to overtime operations and the storage of field-run fruit.

5. Cost functions which specify $A_V$, $B_{1V}$, $B_{2V}$, TSSC, and M, given values for V, R, A, $H_{st}$, and $H_{ot}$.

6. Equations which permit the determination of $X_{mj}$, given values for k, R, and A.

7. The constraints within which the plant must operate.

Certain of the functions and variables listed above have been specified in preceding sections. The largest single unknown at this point is P, the vector specifying the pattern in which any given total quantity of fruit arrives at the plant.

**The Receipts Pattern**

The receipts pattern at any given plant during any given season is assumed to be characterized by the following distribution:

$$\pi : (P, \Sigma_P) \tag{53}$$

where

$\pi$ = (1 x J) vector with the typical entry $\pi_j$ representing the arrival rate on day j expressed relative to the mean rate of arrival $\bar{q}$, that is,

$$\pi_j = \frac{q_j}{\bar{q}} \qquad \bar{q} = \frac{V}{J}, \tag{54}$$

P = (1 x J) vector whose entries $P_j$ represent the expected arrival rate on day j expressed relative to the mean rate of arrival $\bar{q}$, that is,

$$E(\pi_j) = P_j \tag{55}$$

and

$\Sigma_P$ = variance–covariance matrix of the $P_j$.

Actual arrivals on any given day are equal to

$$\begin{aligned} q_j &= P_j \bar{q} + u_j \bar{q} \\ &= \pi_j \bar{q} \end{aligned} \tag{56}$$

where $u_j$ is a random disturbance in $P_j$.

Specifications with respect to the $u_j$ are as follows:

$$\begin{aligned} E(u_j) &= 0 \\ E(u_j, u_j) &= \sigma^2_{P_j} = \text{variance of } P_j;\ j = 1 \ldots J \\ E(u_i, u_j) &= \sigma_{P_j}\sigma_{P_i} = \text{covariance of } P_i \text{ and } P_j \\ & \qquad i = 1 \ldots J,\ j = 1 \ldots J \end{aligned}$$

and

$E(u_{jt}, u_{jt'}) = 0$ for $t \neq t'$ where $u_{jt}$ is the disturbance of $P_j$ in year t.

The vector P is assumed to specify the basic seasonal pattern of receipts at a pear packing plant in a given production region. The entries in this vector are determined by the forces underlying the pattern in daily plant receipts during any given operating season. The principal determinant is the natural seasonal pattern in which the pear crop ripens. This natural pattern may be compounded by inherent differences in the ripening patterns of different orchards within a given supply area.

The disturbance term u is assumed to reflect all of the random elements which tend to disturb the underlying pattern of plant receipts specified by P. These include such things as peculiarities in the weather prior to the harvest season which result in an abnormally large or small proportion of the crop being harvested early in the season, thus shifting the entire pattern or such elements as rain on one or more days during the harvest season which have their major effect on a single day's receipts. These random elements may act to either increase or decrease a given day's receipts. In the model specified, the average effect of these events is assumed to be zero, that is, $E\ (u_j) = 0$. It is also assumed that disturbances in one year have no carry–over effect to succeeding years, hence $E\ (u_{jt},\ u_{jt'}) = 0$ for $t \neq t'$, and that the receipts pattern is independent of the total quantity of receipts, V.

**Estimation of Receipts Pattern.**—For the 1961 study of pear packing operations in Lake County, data on actual receipts during past seasons were obtained from six different pear packing plants operating in the County. Since the same region, subject to the same climatic factors, is used in the current study, the data previously obtained are considered still to be applicable and are used in the present analysis.

Total arrivals differ among plants in any given year and from season to season at any single plant. Actual daily arrivals were converted to relative daily arrival rates by dividing daily receipts in each season by the mean rate of arrival in that season. A season length of 30 days was used in computing the mean daily arrival rate in each of the sample seasons. These computations involved determining:

$$\bar{q}_y = \frac{\sum_{j=1}^{J} q_{jy}}{30} \tag{57}$$

for each season y and dividing the $q_{jy}$ by $\bar{q}_y$ to obtain $\pi_{jy}$, that is,

$$\pi_{jy} = \frac{q_{jy}}{\bar{q}_y} \tag{58}$$

The 38 different seasonal patterns of $\pi_{jy}$ in the sample of receipts data used in this analysis are shown in Appendix E. These data support the assumptions that (1) the seasonal receipts patterns for plants operating in the region studied do not contain a time trend, and (2) receipts at the various plants within the region have the same underlying seasonal pattern and are subject to similar random effects. Given these two assumptions, data from various years and plants are considered jointly in estimating P and $\ddagger_P$.

The vector P was estimated as follows. The expected value of a random vector is equal to the expected value of its elements, that is,

$$E(\pi) = E \begin{bmatrix} \pi_1 \\ \pi_2 \\ \cdot \\ \cdot \\ \cdot \\ \pi_J \end{bmatrix} = \begin{bmatrix} E(\pi_1) \\ E(\pi_2) \\ \cdot \\ \cdot \\ \cdot \\ E(\pi_J) \end{bmatrix} = \begin{bmatrix} P_1 \\ P_2 \\ \cdot \\ \cdot \\ \cdot \\ P_J \end{bmatrix} . \tag{59}$$

With the model used, it can be shown that:

$$\frac{\sum_{y=1}^{Y} \pi_{jy}}{Y} = \hat{P}_j \tag{60}$$

where $\hat{P}_j$ is a linear unbiased estimator of $P_j$ of minimum variance.[1]

The entries in a vector P were estimated from the plant receipts data by summing the $\pi_{jy}$ over plants and seasons and dividing the result by 38, the total number of seasons for which data were obtained. This vector is shown in Table 14.

The entries in this vector, together with a specified value for $\bar{q}$, the mean daily arrival rate, permit specification of the expected actual receipts for each day of the season at a plant operating in the region considered and receiving a total season volume, $V = 30\ \bar{q}$.

**Total Daily Plant Receipts With Projected 1985 Ouput.**—In Section IX it was estimated that one plant located at the transportation–cost–minimizing plant site would minimize the combined assembly and processing costs involved in handling the projected 1985 Lake County pear crop. The single plant would receive 186,122,000 pounds of pears during the 1985 harvest season. With a 30–day season, the projected mean daily arrival rate would be 6,204,000 pounds. These values are assumed to be the total and mean level of arrival in all of the immediately following analyses. In a final simulation the additional problem of variable total annual receipts is considered.

### Penalty Fruit

A given day's receipts may be entirely processed on the day of arrival, partially processed and partially stored, or entirely stored. As previously defined, penalty fruit exists whenever the firm's facilities are insufficient to handle a given day's receipts in one of these three ways. Penalty costs consist of the additional costs or reductions in revenue incurred by the firm as a result of being unable to dispose of a portion of a

[1] The proof of this statement is equivalent to the proof that the sample mean is the best linear unbiased estimator of the population mean.

TABLE 14

Estimated Expected Receipts Pattern for Pear Packing Plants
Lake County, California, 1972

| Day of season | Expected percentage of mean daily receiving rate $E(\pi_j)$ |
|---|---|
| 1 | 20.72 |
| 2 | 33.37 |
| 3 | 45.35 |
| 4 | 61.51 |
| 5 | 75.21 |
| 6 | 90.26 |
| 7 | 98.95 |
| 8 | 107.58 |
| 9 | 109.53 |
| 10 | 115.40 |
| 11 | 120.08 |
| 12 | 122.21 |
| 13 | 124.46 |
| 14 | 127.49 |
| 15 | 132.68 |
| 16 | 131.49 |
| 17 | 136.56 |
| 18 | 142.04 |
| 19 | 138.43 |
| 20 | 138.66 |
| 21 | 131.14 |
| 22 | 124.13 |
| 23 | 122.10 |
| 24 | 114.10 |
| 25 | 105.20 |
| 26 | 94.39 |
| 27 | 82.95 |
| 28 | 62.35 |
| 29 | 54.72 |
| 30 | 36.92 |

Source: Calculated.

given day's receipts in the normal manner. The magnitude of these costs is, in part, subject to a variety of actions which a firm confronted with penalty fruit could take. The most obvious would be to refuse to accept delivery of fruit which it cannot handle. This alternative, however, is not normally open to pear packing firms because in most instances there are packer–grower agreements which specify that the plant will handle the grower's crop as it is harvested. This is particularly true where the plant is owned by a grower cooperative, the dominant form of business organization in the California fresh pear industry.

If the firm must accept all deliveries, there are at least three alternative methods of disposing of excess receipts. The fruit can be stored in nonrefrigerated storage, it can be sold as field–run fruit, or it can be placed in commercial cold storage. Each of these disposal methods involves costs. With the first, costs would be measured in terms of the loss in revenue resulting from the deterioration in fruit quality caused by nonrefrigerated storage. The cost of using the second method of disposal is the difference in net revenue realized by the firm from selling field–run fruit as compared with selling the various products obtained from the grading and packaging operations performed in the packing plant. With the third method, costs would be measured in terms of the transportation and storage costs involved in using commercial cold storage to handle a given day's overflow.

The penalty cost rate with the first two methods of disposal would vary with market conditions and the grade distribution of the fruit while, with the third method, the penalty cost rate depends upon commercial transportation and storage cost rates. With varying market conditions and grade distributions, it is impossible to specify a single cost rate for the first two methods. Therefore, while in practice the method used would depend upon the relative cost rates of the alternative methods, it was assumed that all penalty fruit would be disposed of through use of commercial cold storage. Penalty costs, M per 1,000 pounds of fruit, for a plant operating in the region considered were estimated as \$2.50 for precooling in commercial facilities plus \$5.75 per 1,000 pounds for handling and transportation costs (i.e., M = \$8.25).[1] In simulations involving severe restrictions on refrigeration capacity, some fruit on peak–volume days may have to be diverted field–run to commercial cold storage and then returned for packing. With the additional handling and transportation costs this involves, the penalty cost becomes \$14 per 1,000 pounds of fruit.

### Cost Functions

Planning cost functions developed in Sections IV and V are used to specify values for $A_v$, $B_{1v}$, $B_{2v}$, and TSSC, given values for $V_t$, R, A, $H_{st}$, and $H_{ot}$. Simplifying assumptions are that only bulk–fill methods are used in the packing stage and that, of the total fruit received, 65 percent is packed and 35 percent goes to cannery use and culls. The equations used in specifying the cost parameters of the system then are as follows:

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[1] Includes the following costs per 1,000 pounds of fruit: transportation to Yuba City (Public Utilities Commission rate), \$4.68; unload at storage, \$0.13; precooling, plus up to five days' storage, \$2.50; loading for shipment, \$0.94; total, \$8.25.

$$A_v = 10{,}333 + 1{,}012.1\ V_t \tag{61}$$ [1]

$$B_{1v} = 29.8 + 12.88\ V_t \tag{62}$$ [2]

$$B_{2v} = 44.7 + 14.72\ V_t \tag{63}$$ [3]

$$TSSC = 1{,}133 + 103.2\ R + 756.9\ A + 0.07\ H_s + 0.033\ RH_s \qquad R < 300 \tag{64}$$ [4]

$$TSSC = 168 + 106.4\ R + 756.9\ A + 0.034\ RH_s \qquad R \geqslant 300. \tag{64a}$$ [5]

For analytical purposes, equations (64) and (64a) must be restated so as to relate total season storage cost to operating rates with respect to delivery of field fruit to the packinghouse, capacity rates for packing and storage operations, and hours of plant and storage operation. The estimating and operational models specified thus far lead to the following:

1. The total quantity of fruit processed during the season is

$$V = \sum_{j=1}^{n} q_j = \sum_{j=1}^{n} V_j\ H_j \tag{65}$$

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[1] Derived from equation (18) by substituting $0.35\ V_t$ for $V_c$.

[2] Derived from equation (17) by substituting $0.35\ V_t$ for $V_c$.

[3] Equation (17) adjusted to reflect overtime wage rates 50 percent larger than straight–time wage rates.

[4] Equation (39) repeated here as equation (64).

[5] Equation (39a) repeated here as equation (64a).

where

$V$ = total fruit processed during the season (1,000 pounds)

$q_j$ = total receipts on the $j$th day (1,000 pounds)

$V_j$ = hourly receiving rate on the $j$th day (1,000 pounds per hour)

$H_j$ = hours of packinghouse operation on the $j$th day[1]

and

$n$ = number of days of packinghouse operation per season.

2. Capacity of the storage facility—$SC_1 + SC_2$ in equation (31)—consists of the capacity required to meet the requirements of the maximum-rate, three-day precooling cycle plus the capacity in excess of precooling requirements provided to satisfy marketing strategies or for storage of field-run fruit. Under this specification, the level of storage activity rises to a peak at some point during the season. As receiving rate declines with passage of the peak harvesting rate, field-run fruit previously diverted to cold storage prior to packing will be withdrawn for packing and immediate shipment. Diverted field-run fruit will not be withdrawn for packing before the three-day precool cycle is complete since it would involve additional handling costs to return the partially cooled, packed fruit to storage and again withdraw it for shipment.[2] Similarly, once in cold storage, diverted fruit would not be withdrawn for packing unless excess packing capacity were available. This is because new diversions of field-run fruit made only to "rotate out" prior diversions would involve the additional costs of storing and precooling the 35 percent of field-run fruit destined for cannery shipment.

The simplest model in the following analysis involves the assumption that the shipping rate, $V_s$, on the $j$th day is always equal to or greater than the packing rate on day $j - 3$. Then $SC_2 = 0$ with respect to storage of packed fruit, and equation (31) can be written as:

$$R_j' = 0.173\ L_j' + 0.050\ SC_{1j}' \tag{66}$$

[1] Hours of plant operation are assumed to be the same in all activities, i.e., daily hours receiving = daily hours packing = daily hours shipping. Minor deviations from this pattern should not affect the results of the analysis appreciably.

[2] An exception to this rule might be economical near the end of the packing season in order to complete all packing prior to expeditious release of the packing crew.

where

$R'_j$ = refrigeration load on day j (tons of refrigeration) attributable to packed fruit

$L'_j$ = average daily packed–fruit loading rate on days j – 2, j – 1, j (1,000 pounds of fruit)

and

$SC'_{1j}$ = packed–fruit storage capacity (1,000 pounds of fruit).

3. In the more complex model involving the accumulation of a storage inventory of field–run fruit, the precooling refrigeration load on a given day, j, is based on a moving average consisting of the average daily loading rate on days j – 2, j – 1, and j. The "holding" refrigeration capacity required on a given day, j, is determined by the total storage inventory on day j of packed plus field–run fruit. The total refrigeration capacity required on any day, j, is the sum of the precooling refrigeration load and the necessary holding refrigeration capacity.

Defining the refrigeration capacity (here taken to be the maximum of the daily demands during the operating season) is approached by expressing average daily loading rate, $L'_j$, as:

$$L'_j = \sum_{j-2}^{j} (V_{pj} H_j + V_{dj} H_j) \Big/ 3, \tag{67}$$

but for simplicity throughout the rest of the analysis, using the daily loading rate,

$$L_j = V_{pj} H_j + V_{dj} H_j . \tag{68}$$

The total storage capacity required on a given day, $SC'_{1j}$, then may be written as:

$$SC'_{1j} = \sum_{j-2}^{j} V_{pj} H_j + \sum_{j=1}^{j} V_{dj} H_j - \sum_{j=1}^{j} V_{wj} H_j . \tag{69}$$

The components of required refrigeration capacity, estimated in terms of equations (31) and (66), consist of:

$$R_I = \left( R_{L'_J} + R_{SC'_{1J}} \right) . \tag{70}$$

where

$V_{pj}$ = packing rate on the *j*th day (1,000 pounds per hour)

$V_{dj}$ = rate of diversion of field–run fruit to cold storage on the *j*th day (1,000 pounds per hour)

$V_{wj}$ = rate of withdrawal of diverted fruit for packing on the *j*th day (1,000 pounds per hour)

$R_I$ = installed refrigeration capacity (tons of refrigeration); here taken as the maximum of daily requirements

and

$L'_j$ $SC'_{1j}$, and $H_j$ are as previously defined.

4. The amount of storage space required on a given day, j, is the sum of that required for the packed fruit held in the three–day precooling cycle and the field–run fruit diverted to cold storage because of insufficient packing capacity. Expressed in terms of storage floor area, this is:

$$A_j = a \sum_{j-2}^{j} V_{pj} H_j + b \left( \sum_{j=1}^{j} V_{dj} H_j - \sum_{j=1}^{j} V_{wj} H_j \right) \qquad (71)$$

where

a = floor space required for the storage of 1,000 pounds of fruit packed in cartons = 5.88 square feet[1]

b = floor space required for the storage of 1,000 pounds of fruit in field bins = 3.18 square feet

and

all other variables are as previously defined.

The amount of storage space required to be constructed for a given plant is given as A = maximum $A_j$ over the operating season.

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[1] Floor space required for the storage of 1,000 pounds of fruit packed in standard boxes = 4.40 square feet. The storage space coefficients specified include allowance for a 12–foot–wide center aisle required for forklift operations.

5. Variable storage costs, as expressed in equation (38), are a function of refrigeration equipment capacity and hours of operation per season. Machine equipment capacity, however, is determined by peak loading rates and maximum holding requirements. This means that less than the installed refrigeration capacity will be required on most days during the season, and the equipment will operate intermittently. An appropriate simplification is to assume that power requirements with intermittent operation of the full–capacity installation can be approximated by an equivalent computation based on estimated daily required refrigeration capacity operating continuously for 24 hours. Equations (38) and (38a) then may be used to express total season variable costs as follows:

$$TSVSC = 0.07\ H_s + 0.033 \sum_{j=1}^{N+3} R_j\ H_{js} \qquad R_I < 300 \tag{72}$$

$$TSVSC = 0.034 \sum_{j=1}^{N+3} R_j\ H_{js} \qquad R_I \geqslant 300 \tag{72a}$$

where

$TSVSC$ = total season variable storage costs (dollars)

$H_s$ = hours of storage operation per season

= 24 (N + 3)

$N$ = number of calendar days in the packing season (n + K)

$n$ = number of days of packinghouse operation per season

$K$ = number of days during the season on which no fruit was packed

$R_j$ = refrigeration capacity required on the *j*th day (tons of refrigeration)

$R_I$ = installed refrigeration capacity (tons of refrigeration)

and

$H_{js}$ = hours of storage operation on the *j*th day = 24.

The preceding expressions define the variables of equations (39) and (39a) in terms of season and plant operating conditions. By substitution, these equations can be written as follows:

$$TSSC = 1{,}133 + 103.2\ R_I + 756.9\ A + TSVSC \qquad R_I < 300 \tag{73}$$

$$TSSC = 168 + 106.4\ R_I + 756.9\ A + TSVSC \qquad R_I \geqslant 300. \tag{73a}$$

## Operating Rules––Plant

The operating rule for a plant of a given hourly capacity affects the hours of straight–time and overtime operation required to process a given total quantity of fruit and also affects storage and penalty costs. The operating rules and associated variable cost rates are the following:

1. Process all fruit on the day of arrival which can be processed within 16 hours; store all fruit which cannot be processed within 16 hours. Use a double–shift operation to adjust daily processing capacity to daily receipts for a processing time of 8–16 hours. Variable costs per hour for straight–time or first–shift operation, as derived from equation (23), are:

$$29.8 + 18.2\ V_p + 3.0\ V_c \tag{74}$$

   and for second–shift operation:

$$31.3 + 18.4\ V_p + 3.15\ V_c. \tag{75}$$

2. Work no overtime; use storage operations to adjust daily flow of fruit to daily processing capacity, i.e., operate up to 8 hours; divert the remainder to storage. Costs are calculated according to equation (74).

3. Work 1 or 2 hours of overtime on days when receipts are large enough to require either 9 or 10 hours of operation; store all field–run fruit which cannot be processed within 10 hours. Variable costs per hour of overtime operation are computed from:

$$44.658 + 4.542\ V_c + 20.2\ V_p\ . \tag{76}$$

   In the above:

   $V_t$ = total packinghouse output (1,000 pounds per hour)

   $V_c$ = .35 V = volume of cannery and cull fruit run (1,000 pounds per hour)

and

   $V_p$ = .65 $V_t$ = volume of fruit packed for fresh shipment (1,000 pounds per hour).

   all expressed as capacity rates of operation.

Many other rules could have been considered; however, those listed include the extreme positions with respect to the use of overtime and storage operations.

## Operating Contraints

The following constraints specify the limits within which the plant is assumed to operate:

1. A minimum operating period of 4 hours is required on each day the plant is operated.

2. The smallest pay period is one–quarter of an hour.

3. Overtime wage rates must be paid for all operations in excess of 8 hours on any given day.

4. Saturday operations do not require payment of overtime wage rates.

5. The plant must operate on each day of the season, except Sunday, on which fruit is received.

6. All field–run fruit must be processed within 15 days of the last day on which fruit is received by the plant.

## The Simulation Procedure––An Example

A cost simulation analysis is presented below by (1) first considering an example involving a specific plant operating rule and plant capacity and (2) applying guidelines established in the example to less restricted simulations aimed at specifying cost–minimizing operating conditions. In this and the following simulations, these analyses are restricted to plant costs only, omitting assembly costs. This simplifies the calculations without affecting the outcome.

The example presented in Table 15 involves a plant with an hourly capacity of 490,000 pounds per hour. Operating rule 3 is specified which permits up to 10 hours of plant operation per day and provides for storage of field–run fruit when daily receipts exceed packing capacity.

**Expected Daily Receipts and Hours of Operation.**––Expected daily receipts, generated by means of the vector $\hat{P}$ presented in Table 14 and a mean daily arrival rate of 6,204,000 pounds, are given in column 1 of Table 15. Hours of straight–time operation, column 2, are computed by dividing hourly plant capacity into daily receipts and rounding to the next highest quarter hour for all values between 4.0 and 8.0. In compliance with the specified constraint, the minimum daily plant operation is 4 hours per day.

Hours of overtime operation are specified on the basis of the decision rule. For example, on the fifth day receipts are greater than can be handled in 9 hours of operation but not sufficient to require 10 hours of operation. Thus, on this day receipts exceeding those which can be processed in 9 hours are stored. On the sixth day receipts exceed plant capacity with 10 hours of operation; therefore, on this day 2 hours of overtime, as well as field–run storage, are required in the simulated solution.

TABLE 15

Simulated Pear Packing Plant Operations With Hourly Capacity of 490,000 Pounds Operating Up to 10 Hours Per Day and Receiving 186,122,000 Pounds of Fruit in the Estimated Expected Seasonal Pattern Lake County, California, 1972

| Day of season | Daily receipts | Straight-time operation | Overtime operation | Daily storage loading rate: Field run | Daily storage loading rate: Packed fruit | Storage inventory: Field run | Storage inventory: Packed fruit | Area required | Refrigeration required |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | 1,000 pounds | hours | | 1,000 pounds | | | | 1,000 square feet | tons |
| 1 | 1,285 | 4.00 | 0 | 0 | 835 | 0 | 835 | 5 | 186 |
| 2 | 2,070 | 4.25 | 0 | 0 | 1,345 | 0 | 2,181 | 13 | 342 |
| 3 | 2,814 | 5.75 | 0 | 0 | 1,829 | 0 | 4,010 | 24 | 517 |
| 4 | 3,816 | 8.00 | 0 | 0 | 2,548 | 0 | 5,723 | 34 | 727 |
| 5 | 4,666 | 8.00 | 1.00 | 256 | 2,866 | 256 | 7,244 | 45 | 915 |
| 6 | 5,600 | 8.00 | 2.00 | 700 | 3,185 | 956 | 8,600 | 59 | 1,150 |
| 7 | 6,139 | 8.00 | 2.00 | 1,239 | 3,185 | 2,195 | 9,236 | 74 | 1,337 |
| 8 | 6,674 | 8.00 | 2.00 | 1,774 | 3,185 | 3,969 | 9,555 | 91 | 1,526 |
| 9 | 6,795 | 8.00 | 2.00 | 1,895 | 3,185 | 5,864 | 9,555 | 104 | 1,618 |
| 10 | 7,159 | 8.00 | 2.00 | 2,259 | 3,185 | 8,123 | 9,555 | 117 | 1,753 |
| 11 | 7,450 | 8.00 | 2.00 | 2,550 | 3,185 | 10,673 | 9,555 | 130 | 1,873 |
| 12 | 7,582 | 8.00 | 2.00 | 2,682 | 3,185 | 13,355 | 9,555 | 143 | 1,967 |
| 13 | 7,722 | 8.00 | 2.00 | 2,822 | 3,185 | 16,177 | 9,555 | 155 | 2,058 |
| 14 | 7,910 | 8.00 | 2.00 | 3,010 | 3,185 | 19,187 | 9,555 | 167 | 2,157 |
| 15 | 8,232 | 8.00 | 2.00 | 3,332 | 3,185 | 22,519 | 9,555 | 182 | 2,290 |
| 16 | 8,158 | 8.00 | 2.00 | 3,258 | 3,185 | 25,777 | 9,555 | 195 | 2,347 |
| 17 | 8,472 | 8.00 | 2.00 | 3,572 | 3,185 | 29,349 | 9,555 | 209 | 2,481 |
| 18 | 8,812 | 8.00 | 2.00 | 3,912 | 3,185 | 33,261 | 9,555 | 225 | 2,625 |
| 19 | 8,588 | 8.00 | 2.00 | 3,688 | 3,185 | 36,949 | 9,555 | 239 | 2,664 |
| 20 | 8,603 | 8.00 | 2.00 | 3,703 | 3,185 | 40,652 | 9,555 | 252 | 2,733 |
| 21 | 8,136 | 8.00 | 2.00 | 3,236 | 3,185 | 43,888 | 9,555 | 258 | 2,685 |
| 22 | 7,701 | 8.00 | 2.00 | 2,801 | 3,185 | 46,689 | 9,555 | 262 | 2,628 |
| 23 | 7,575 | 8.00 | 2.00 | 2,675 | 3,185 | 49,364 | 9,555 | 264 | 2,618 |
| 24 | 7,079 | 8.00 | 2.00 | 2,179 | 3,185 | 51,543 | 9,555 | 265 | 2,535 |
| 25 | 6,527 | 8.00 | 2.00 | 1,627 | 3,185 | 53,170 | 9,555 | 263 | 2,428 |
| 26 | 5,856 | 8.00 | 2.00 | 956 | 3,185 | 54,126 | 9,555 | 256 | 2,271 |
| 27 | 5,146 | 8.00 | 2.00 | 246 | 3,185 | 54,372 | 9,555 | 246 | 2,089 |
| 28 | 3,868 | 8.00 | 2.00 | 52 | 2,548 | 54,320 | 8,918 | 232 | 1,851 |

(Continued on next page.)

TABLE 15--continued.

| Day of season | Daily receipts | Straight-time operation | Overtime operation | Daily storage loading rate: Field run | Daily storage loading rate: Packed fruit | Storage inventory: Field run | Storage inventory: Packed fruit | Area required | Refrigeration required |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | 1,000 pounds | hours | | 1,000 pounds | | | | 1,000 square feet | tons |
| 29 | 3,395 | 8.00 | 0 | - 525 | 2,548 | 53,795 | 8,281 | 218 | 1,787 |
| 30 | 2,291 | 8.00 | 0 | -1,629 | 2,548 | 52,166 | 7,644 | 201 | 1,747 |
| 31 | 0 | 8.00 | 0 | -3,920 | 2,548 | 48,246 | 7,644 | 175 | 1,746 |
| 32 | 0 | 8.00 | 0 | -3,920 | 2,548 | 44,326 | 7,644 | 163 | 1,738 |
| 33 | 0 | 8.00 | 0 | -3,920 | 2,548 | 40,406 | 7,644 | 150 | 1,710 |
| 34 | 0 | 8.00 | 0 | -3,920 | 2,548 | 36,486 | 7,644 | 138 | 1,643 |
| 35 | 0 | 8.00 | 0 | -3,920 | 2,548 | 32,566 | 7,644 | 125 | 1,577 |
| 36 | 0 | 8.00 | 0 | -3,920 | 2,548 | 28,646 | 7,644 | 113 | 1,510 |
| 37 | 0 | 8.00 | 0 | -3,920 | 2,548 | 24,726 | 7,644 | 101 | 1,443 |
| 38 | 0 | 8.00 | 0 | -3,920 | 2,548 | 20,806 | 7,644 | 88 | 1,377 |
| 39 | 0 | 8.00 | 0 | -3,920 | 2,548 | 16,886 | 7,644 | 76 | 1,310 |
| 40 | 0 | 8.00 | 0 | -3,920 | 2,548 | 12,966 | 7,644 | 63 | 1,243 |
| 41 | 0 | 8.00 | 0 | -3,920 | 2,548 | 9,046 | 7,644 | 51 | 1,177 |
| 42 | 0 | 8.00 | 0 | -3,920 | 2,548 | 5,126 | 7,644 | 38 | 1,110 |
| 43 | 0 | 8.00 | 0 | -3,920 | 2,548 | 1,206 | 7,644 | 26 | 1,043 |
| 44 | 0 | 4.00 | 0 | -1,206 | 784 | 0 | 5,880 | 27 | 583 |
| 45 | 0 | 0 | 0 | 0 | 0 | 0 | 3,332 | 20 | 254 |
| 46 | 0 | 0 | 0 | 0 | 0 | 0 | 784 | 5 | 60 |
| 47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Cost data

| | | |
|---|---|---|
| Plant costs (1,000 dollars) | | |
| Annual fixed costs | $ 506 | |
| Annual variable costs | | |
| Straight time | 2,143 | |
| Overtime | 326 | |
| Total | | $2,976 |
| Storage costs (1,000 dollars) | | |
| Refrigeration provided | 2,733 tons | |
| Annual variable costs | $ 70 | |
| Annual fixed costs | 492 | |
| Total | | 562 |
| Penalty cost (1,000 dollars) | | |
| Maximum required refrigeration | 2,733 tons | |
| Refrigeration provided | 2,733 tons | |
| Maximum required area | 263,000 square feet | |
| Area provided | 263,000 square feet | |
| Penalty fruit | 0 | |
| Penalty cost | 0 | |
| TOTAL ANNUAL COST | | $3,538 |

Source: Calculated.

The daily storage loading rate for field–run fruit is equal to total daily receipts minus the quantity processed. For example, on the sixth day expected receipts are estimated to be 5,600,000 pounds. With 10 hours of operation, daily plant capacity is 4,900,000 pounds leaving 700,000 pounds of field–run fruit to be stored. Expected daily storage loading rates for field–run fruit, thus determined from the plant capacity and the operating rule considered here, are shown in column 4 of Table 15. The total quantity of field–run fruit in storage on any given day, j′, is determined by:

$$\sum_{j=1}^{j'} (q_j - VH_j) \tag{77}$$

subject to the general operating constraints and the constraint that the inventory on any given day cannot be less than zero. A negative value for $q_j - VH_j$ would indicate a withdrawal of field–run fruit from storage on day j. Column 4 of Table 15 indicates that, given the size of plant and the operating rule considered, field–run fruit flows into storage during the middle of the season. It is withdrawn during the latter part of the season as receipts decline and after the close of the delivery season.

The packed fruit loading rate is equal to:

$$PF_j = V_{pj} H_j = 0.65 V_t H_j \tag{78}$$

where $PF_j$ is fruit packed on day j in 1,000 pounds.

This equation is based on the assumption that 65 percent of the fruit received is packed and that all packed fruit moves through the cold storage precooling cycle. Packed fruit is assumed to be stored three days prior to shipment. Thus, the packed fruit inventory at the end of any given day is:

$$PFI_j = 0.65 V_t (H_j + H_{j-1} + H_{j-2}) \tag{79}$$

where $PFI_j$ is packed fruit inventory on day j.

The expected packed fruit loading rate for each day of the season, given the facilities considered in this example, is shown in column 5 of Table 15; and the cumulative inventory is shown in columns 6 and 7.

**Cost Calculations.**—The information in Table 15, together with previously indicated cost functions, provides the basis for estimating minimum expected costs for a plant having hourly capacity of 490,000 pounds operated under rule 3. Thus:

**Plant Costs.**—Fixed plant costs per season and total variable costs for both straight–time and overtime operations are determined directly from equations (61), (62), and (76). Total hours of straight–time and overtime operation are determined by summing the appropriate columns of Table 15. Total season plant costs are determined by multiplying hours of straight–time and overtime operation by the appropriate hourly variable cost figure to obtain operating costs and adding fixed cost per season.

**Storage Costs.**——Peak storage space requirements occur on the 27th day of the season when there are 54,372,000 pounds of field–run fruit in storage and 9,555,000 pounds of packed fruit in storage. By equation (71), storage floor space requirements are specified to be 246,000 square feet. The maximum refrigeration requirement, 2,733 tons on the 20th day, is estimated from equation (70).

Hours of storage operation are determined by multiplying by 24 the number of days the packing plant is operated plus the number of days fruit is held in storage after packing plus 1 additional day for every 6 days of plant operation to account for Sunday operation of the storage. In this particular run the plant is operated 44 days. Allowing seven days for Sunday operation and three days of storage after the final packing day, total hours of storage operation are:

$$H_s = (54 \times 24) = 1{,}176 . \tag{80}$$

Total expected storage costs are obtained by substituting the computed values for R, A, and $H_s$ in equation (73a).

**Penalty Costs.**——In the particular example given in Table 15, refrigeration and area capacities are set equal to the maximum required. Thus, penalty fruit and costs are equal to zero.

**Expected Total Season Costs.**——The sum of computed plant, storage, and penalty costs yields an estimated minimum total expected cost of $3,538,000. The specified total season volume is 186,122,000 pounds of pears; the seasonal pattern is specified by $\hat{P}$ (Table 14); and the packinghouse has an hourly capacity of 490,000 pounds and is operated under rule 3 which permits up to 10 hours of operation per day.

## Minimization of Expected Costs

Because of the interrelationships between receipts and storage and plant costs, it would be impossible to deduce a cost–minimizing (V, R, A) solution. One could iterate over all allowable (V, R, A) combinations. However, the very large number of computations this would require can, for practical purposes, be reduced through appropriate design of the simulation process. Thus, in this application note from equations (31), (65), (68), and (69) that:

$$R_j = .173\ L'_j + .05\ SC'_{1j} + 0.017\ SC'_{2j}$$

or

$$R_j = .173\ (V_{pj}\ H_j + V_{dj}\ H_j) + .05 \left( \sum_{j-2}^{j} V_{pj}\ H_j + \sum_{j-2}^{J} V_{dj}\ H_j \right) + 0.017 \left( \sum_{j=1}^{j-2} V_{dj}\ H_j - \sum_{j=1}^{j-2} V_{wj}\ H_j \right) . \tag{81}$$

but that, in general, there is no solution to $V_{pj} H_j$ in terms of predetermined variables. If, to simplify matters, $V_t$ is chosen so that all incoming fruit is processed and there is no storage of field–run fruit, i.e., $V_{dj} = V_{wj} = 0$, then equation (81) can be written as:

$$R_j = .173 V_{pj} H_j + .05 \sum_{j-2}^{j} V_{pj} H_j. \tag{82}$$

Since on day j, $V_{pj-1}$ and $V_{pj-2}$ are already determined, write:

$$V_{pj} H_j = \frac{1}{.223} \left( R_j - .05 \sum_{j-2}^{j-1} V_{pj} H_j \right). \tag{83}$$

If refrigeration capacity is given at some $R_I$ and $R_j \leqslant R_I$ is constrained, then the volume of packed fruit which enters on–site cold storage is:

$$PF_j = \frac{1}{.223} \left( R_I - .05 \sum_{j-2}^{j-1} V_{pj} H_j \right). \tag{84}$$

The volume of penalty fruit going to commercial storage is $V_{pj} H_j - PF_j$. Penalty cost is computed at $8.25 per 1,000 pounds of fruit. Area required on day j ($A_j$) is given by equation (71). The capacity area is unconstrained at the maximum $A_j$.

**Effect of Variation in Refrigeration and Packing Capacities**

The example in Table 15 is based on the condition that storage and packing capacity will be provided sufficient to meet maximum daily requirements over the entire season. While this avoids penalty costs, it also provides excess capacity on all but the peak day. To consider cost levels if storage and packing capacities were constrained to some level below the season maximum, two additional trial simulations were run. In one trial, packinghouse capacity was fixed at the respective rates corresponding to the three operating rules (rule 1, 1,102,000; rule 2, 3,551,000; and rule 3, 882,000 pounds per hour, respectively). Costs were then simulated with different refrigeration capacities beginning with $R_I$ equal to zero and, with each succeeding simulation, increasing $R_I$ by 200 tons.

Similarly, under each operating rule a simulation of total season cost was run under the assumption that refrigeration capacity would be fixed at the season maximum requirement and the effects of variation in packinghouse capacity examined by comparing cost estimates over a range of packinghouse capacities (packinghouse capacity varied by increments of 100,000 pounds per hour).

In both of these trials, total season cost under each operating rule—over the range of values assigned to the variable being studied—fell into a shallow, U–shaped pattern with a minimum value at an intermediate (or "saddle") point within the whole range of assigned values. In both trials, season total costs were consistently least with operating rule 1 (2–shift operation with all fruit processed on the day of arrival).[1] Total season costs in the neighborhood of the saddle point defined in these two trials are summarized in Table 16. With refrigeration capacity variable, the cost minimum occurs with 1,700 tons capacity (400 tons less than when $V_t$ is varied and $R_I$ is unconstrained). With packinghouse capacity variable and refrigeration capacity fixed at the season maximum requirement, the cost minimum occurs with a plant capacity of 440,000 pounds per hour (compared with an average daily receipts rate of 551,000 pounds per hour).

These trial results suggest that, even though higher wage rates are paid second–shift workers, the more intensive use of smaller facilities operating up to 16 hours per day provides the most economical solution among the three operating rules considered. Also, as packing and refrigeration capacities are constrained, costs decrease to a minimum and thereafter rise as capacities are further reduced. However, the advantage in constraining refrigeration capacity is slight. Convenience and other minor considerations not specifically included in the analysis suggest that refrigeration capacity corresponding to the season maximum requirements would represent a good approximation of cost minimization under the assumptions of these trial runs.

**Effect of Variation in Daily Receipts Pattern.**—The foregoing simulations are based on a fixed annual volume (projected output, 1985) and the average of a sample of daily receipts patterns. However, the actual pattern of daily receipts is variable, and it is of interest to examine the effect of this variation on total season costs. This is done on the basis of a sample of 15 of the 38 seasonal distributions given in Appendix Table E. The simulation model involves the specification of packinghouse hourly capacity as 440,000 pounds, the use of operating rule 1 (2–shift operation, up to 16 hours per day). Storage capacity is selected to conform with the optimum defined in Table 16. Provision is made for on–site storage of field–run fruit or the shipment of packed fruit to commercial cold storage if required because of limited packing or on–site precool capacity (either or both types of adjustment may be required on days when receipts exceed 6,080,000 pounds—the daily capacity with 65 percent packed fruit and 16 hours per day of operation). This model provides on–site packing–refrigeration capacities sufficient to preclude the shipment of field–run fruit to commercial cold storage.

The results of the 15 simulations are given in Table 17. Penalty costs are generated in 10 of the 15 simulations but in most instances are relatively small. The average of total season costs in the 15 simulations is \$3,438,000. The deviations from this average are relatively small (range \$3,246,000 to \$3,836,000) as are their differences from the preceding simulations based on the distribution pattern averaged over the total of 38 distributions. Given the consistency of these results, all further analyses are simplified by using the average daily receipts distribution pattern.

**Effect of Constraint on Refrigeration Capacity.**—In the simulation summarized in Table 17, the effects of variation in seasonal distribution of daily receipts are observed, given a packing capacity of 440,000 pounds per hour, operation under rule 1 (2 shifts

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[1] For example, in the simulations in which plant capacity is fixed and refrigeration capacity set at the maximum daily requirements, minimum total season costs with each operating rule were as follows: rule 1, \$3,270,000; rule 2, \$3,598,000; and rule 3, \$3,531,000.

TABLE 16

Simulated Pear Packing Plant Operations Under Operating Rule 1
and With Alternative Assumptions Regarding
Packing and Refrigeration Capacities
Lake County, California, 1972

| Packinghouse capacity = season maximum requirement; with selected values for refrigeration capacity[a] | | | Refrigeration capacity = season maximum requirement; with selected values for packinghouse capacity[b] | | |
|---|---|---|---|---|---|
| Packing capacity | Refrig-eration capacity | Total season costs | Refrig-eration capacity | Packing-house capacity | Total season costs |
| 1,000 pounds per hour | tons | 1,000 dollars | tons | 1,000 pounds per hour | 1,000 dollars |
| 551 | 0 | 4,021 | 2,507 | 350 | 3,268 |
| 551 | 500 | 3,685 | 2,363 | 380 | 3,258 |
| 551 | 1,000 | 3,502 | 2,272 | 400 | 3,258 |
| 551 | 1,500 | 3,344 | 2,182 | 420 | 3,255 |
| 551 | 1,600 | 3,329 | 2,100 | 440 | 3,254[c] |
| 551 | 1,700 | 3,324[c] | 2,024 | 460 | 3,261 |
| 551 | 1,800 | 3,328 | 1,899 | 500 | 3,284 |
| 551 | 1,850 | 3,333 | 1,818 | 560 | 3,351 |

[a]Packing capacity, $V_t$, set equal to rate of output required to pack all fruit received on day of arrival. (Under operating rule 1, $V_t$ = 551,000 pounds fruit run per hour in 16 hours per day of packinghouse operation.)

[b]Packing capacity, $V_t$, selected over a range of values, with refrigeration capacity that amount required to handle total daily receipts. (Penalty costs thus are zero.) Full range of values of packing capacities considered = 300,000 to 600,000 pounds per hour.

[c]Cost minimum.

Source: Calculated.

TABLE 17

Total Season Pear Packing Costs as Affected by Variation in Daily Receipts Pattern Lake County, California, 1972

| Daily receipts sample number[a] | Plant costs | Storage costs | Penalty costs[b] | Total[c] |
|---|---|---|---|---|
| | dollars | | | |
| 1 | 2,893,394 | 376,115 | 8,668 | 3,278,177 |
| 2 | 3,124,787 | 357,732 | 13,270 | 3,495,789 |
| 3 | 2,951,404 | 345,249 | 0 | 3,296,653 |
| 4 | 2,977,100 | 350,990 | 0 | 3,328,090 |
| 6 | 3,025,747 | 360,261 | 5,356 | 3,391,364 |
| 10 | 3,051,384 | 380,446 | 1,869 | 3,433,699 |
| 11 | 3,041,767 | 402,697 | 50,059 | 3,494,523 |
| 17 | 2,889,596 | 356,790 | 0 | 3,246,386 |
| 19 | 2,968,101 | 395,435 | 40,535 | 3,404,071 |
| 23 | 3,018,404 | 396,838 | 55,139 | 3,470,381 |
| 24 | 2,942,656 | 390,306 | 27,811 | 3,360,773 |
| 30 | 3,091,525 | 444,303 | 300,209 | 3,836,037 |
| 32 | 3,117,454 | 388,886 | 18,011 | 3,524,351 |
| 37 | 3,071,676 | 428,278 | 146,083 | 3,646,037 |
| 38 | 2,992,586 | 367,706 | 3,631 | 3,363,923 |
| Average | | | | 3,438,016 |

[a] Daily distributions randomly drawn from Appendix Table E.

[b] Penalty costs computed at $8.25 per 1,000 pounds.

[c] Range: $3,246,386-$3,836,037.

Source: Calculated; packing capacity rate = 440,000 pounds per hour under operating rule 1, $R_I$ = 2,101 tons, and A = 145,000 square feet.

with a maximum of 16 hours of operation per day), provision for the storage of field–run fruit when daily receipts exceed packing capacity, and the provision of refrigeration capacity equal to the maximum daily demand. However, to install refrigeration capacity equal to the maximum single day's demand may prove to be uneconomical; therefore, another simulation—with $R_I$ constrained to a succession of prescribed increments below the maximum required—is presented in Table 18. This solution also involves a series of runs with different packing plant capacities so that cost effects of the interaction between packinghouse and refrigeration capacity can be observed in relation to daily receipts estimated by applying the average daily receipts pattern given in Table 14 to the projected 1985 District volume of 186,122,000 pounds.

Examination of row entries in Table 18 shows that, with a given refrigeration capacity, estimated total season cost declines to a minimum and then rises as packinghouse capacity increases. Similarly, in each column—with a given packinghouse capacity—estimated total season cost decreases to a minimum and then rises as installed refrigeration capacity decreases from the maximum considered. The cost–minimizing combination occurs with a packinghouse capacity rate of 440,000 pounds of fruit run per hour and refrigeration capacity in the range of 1,864 to 1,914 tons. These results indicate that, when a variable daily receipts pattern is considered, it is economical to constrain refrigeration capacity below the maximum daily requirement and, on high–volume days, to incur penalty costs through the shipment of packed fruit to commercial cold storage for precooling.

## Year–to–Year Variation in Total Season Volume

In the preceding simulations the effect of shifts in the values of key variables on total District season costs is studied under the assumption of constant annual total volume of fruit production. However, the real situation is one of high variability in annual production, and it is of interest to study the effects of this variability on costs and plant design. Since our interest is long run and focused on a projected "normal" production in 1985, historical data on which to base directly an estimate of the variability of annual production are not available. A proxy, however, was constructed using historical yield data for the period 1940 to 1959.

### Synthesized Variable Annual Production

The synthesis of variable annual production involved (1) using time series data on pear production per mature acre in Lake County to obtain a regression equation for average yield in relation to time (Stollsteimer, 1961), (2) computing the percentage deviation of specific observations from the trend line, and (3) then applying this percentage to the projected 1985 production (186,122,000 pounds) to synthesize a distribution of annual District outputs over a 20–year period. While this proxy of variable annual output, shown graphically in Figure 9, has no merit in the prediction of successive annual outputs of pears in Lake County, it should provide a realistic synthesis of the variability of the 1985 projected normal annual production.

TABLE 18

Simulation of Total Season Plant Cost of Packing Fresh Pears in Relation to Variation in Packing and Refrigeration Capacities Given Average Variation in Daily Receipts Pattern Lake County, California, 1972[a]

| Refrigeration capacity | Total season cost with specified packing capacities 1,000 pounds per hour capacity[b] | | | | | |
|---|---|---|---|---|---|---|
| | 300 | 340 | 380 | 420 | 460 | 500 |
| tons | 1,000 dollars | | | | | |
| 2,464 | 3,320 | 3,290 | 3,290 | 3,303 | 3,324 | 3,355 |
| 2,364 | 3,328 | 3,290 | 3,279 | 3,292 | 3,313 | 3,344 |
| 2,264 | 3,340 | 3,294 | 3,273 | 3,281 | 3,302 | 3,333 |
| 2,164 | 3,356 | 3,302 | 3,272 | 3,271 | 3,291 | 3,322 |
| 2,064 | 3,374 | 3,315 | 3,276 | 3,264 | 3,280 | 3,311 |
| 1,964 | 3,397 | 3,330 | 3,285 | 3,263 | 3,270 | 3,300 |
| 1,864 | 3,433 | 3,350 | 3,297 | 3,269 | 3,266 | 3,290 |
| 1,764 | 3,477 | 3,385 | 3,316 | 3,279 | 3,267 | 3,284 |
| 1,664 | 3,705 | 3,427 | 3,350 | 3,300 | 3,280 | 3,291 |
| 1,564 | 4,245 | 3,473 | 3,392 | 3,334 | 3,305 | 3,308 |
| 1,464 | 4,923 | 3,524 | 3,437 | 3,371 | 3,336 | 3,330 |

[a]Based on 65 percent packed fruit; average variation in daily receipts; use of operating rule 1 (2-shift operation, 16 hours per day); provision for on-site storage of both packed and field-run fruit and for the shipment of packed fruit to commercial storage (with penalty cost = \$8.25 per 1,000 pounds) and field-run fruit to commercial storage and return for packing (with penalty cost = \$14 per 1,000 pounds).

[b]Cost minimum occurs with packinghouse and refrigeration capacity combinations great enough to preclude shipment of field-run fruit to commercial facilities for temporary storage prior to packing. Computed minimum not shown because of omission of alternate cells in the interest of conciseness.

Source: Calculated.

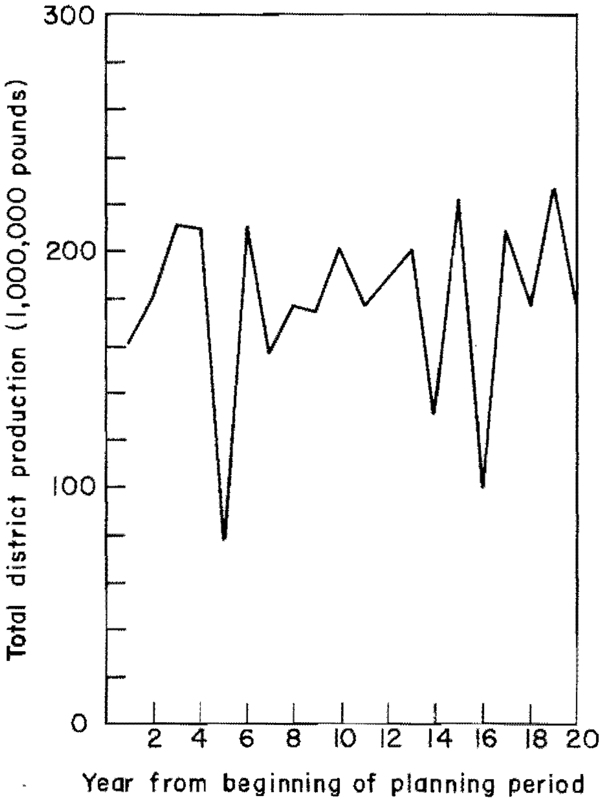


FIGURE 9. SYNTHESIZED VARIABLE ANNUAL PRODUCTION OVER A 20-YEAR PLANNING HORIZON, LAKE COUNTY, CALIFORNIA

**Simulation Analyses**

Each of the 20 synthesized annual outputs was made the basis of a simulation analysis of total season cost in relation to different design combinations of packing and refrigeration capacities. The results (a portion of which are given in Table 19 in terms of both District total season cost and average costs per 1,000 pounds of fruit) indicate that packing and refrigeration capacities affect both the level and the interseasonal variability of estimated total season costs, the effects becoming increasingly apparent as capacity restriction is increased. This is particularly evident in the average cost data of Table 19 when packing or refrigeration capacity constraints are severe and force uneconomical levels of penalty cost.

Summary results for the entire array of capacity combinations considered, expressed in terms of the 20–year average total season cost, are given in Table 20. The averages of estimated total season costs peak sharply in the lower left section of the table which again illustrates the effect of restriction of packing and refrigeration capacities such as to generate excessive penalty–fruit costs. The minimum estimated 20–year average of total season costs occurs with a packing capacity of 420,000 pounds per hour and refrigeration capacity of 2,200 tons. However, the values in adjacent cells indicate the cost surface to be relatively flat so that capacity combinations over a substantial range might be selected with only minor changes in the average of total season costs.

The distribution of estimated costs in Table 20 suggests that selection of design capacities over a wide range of combinations of packing and refrigeration capacities would, in terms of the average experience over a 20–year period, yield closely comparable results with respect to total District season costs. Further, with respect to the design decision on plant capacity, a solution simply calculated on the basis of average annual production, the average daily receipts pattern, and a constraint on refrigeration capacity roughly 20 percent below the maximum daily requirement provides a good approximation of least–cost design (compare Tables 18, 20, and 21).

The foregoing simulations specified a single plant serving the entire District. While different numerical results would be obtained if additional plants were introduced, the suboptimal solutions considered in Section IX demonstrate that a substantial increase in plant numbers could occur with only minor effects on total District season costs. This indicates that the general findings of the simulation results would be applicable even though plant numbers were increased to a moderate degree.

**Recapitulation**

The results of several of the numerous alternative solutions reported above are summarized in Table 21. Again, these data suggest that a wide range of operating conditions can be imposed without substantial effect on total District season costs. This apparent stability is, in part, attributable to the fact that total season variable costs within the range of operating conditions specified vary almost directly with total volume processed. Hence, the variation in total season costs among the various models is a function almost exclusively of the fixed costs. A consistent advantage is demonstrated for 2–shift operation (up to 16 hours per day) as compared with operation under policies which restrict hours of packinghouse operation to 1 shift and no overtime (up to 8 hours per day) or 1 shift with up to 2 hours of overtime per day (a maximum of 10 hours of operation per day).

TABLE 19

The Effect of Variation in Annual District Production on Costs of Packing and Precooling Fresh Pears in Relation to Variation in Packing and Refrigeration Capacities Using Average Daily Receipts Pattern and Synthesized Variation in Annual Production, Lake County, California (1972 Price Level)[a]

| Year | Total season cost | | | | | | Average cost per 1,000 pounds of fruit run | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Refrigeration capacity = 2,200 tons | | | Refrigeration capacity = 1,400 tons | | | Refrigeration capacity = 2,200 tons | | | Refrigeration capacity = 1,400 tons | | |
| | Packing capacity in 1,000 pounds per hour | | | | | | Packing capacity in 1,000 pounds per hour | | | | | |
| | 300 | 420 | 540 | 300 | 420 | 540 | 300 | 420 | 540 | 300 | 420 | 540 |
| | 1,000 dollars | | | | | | dollars | | | | | |
| 1 | 2,792 | 2,854 | 2,996 | 2,897 | 2,797 | 2,921 | 17.75 | 18.06 | 18.92 | 18.33 | 17.68 | 18.44 |
| 2 | 3,178 | 3,152 | 3,274 | 4,138 | 3,226 | 3,247 | 17.85 | 17.69 | 18.29 | 23.17 | 18.05 | 18.13 |
| 3 | 4,150 | 3,693 | 3,679 | 11,513 | 4,000 | 3,824 | 19.85 | 17.68 | 17.62 | 55.10 | 19.12 | 18.27 |
| 4 | 4,072 | 3,683 | 3,675 | 11,383 | 3,988 | 3,816 | 19.52 | 17.67 | 17.63 | 54.58 | 19.10 | 18.26 |
| 5 | 1,641 | 1,793 | 1,959 | 1,553 | 1,705 | 1,871 | 21.19 | 23.16 | 25.30 | 20.06 | 22.02 | 24.16 |
| 6 | 4,026 | 3,676 | 3,669 | 11,278 | 3,979 | 3,807 | 19.33 | 17.67 | 17.63 | 54.17 | 19.09 | 18.25 |
| 7 | 2,758 | 2,827 | 2,966 | 2,841 | 2,762 | 2,888 | 17.78 | 18.15 | 18.99 | 18.24 | 17.71 | 18.49 |
| 8 | 3,109 | 3,103 | 3,226 | 3,669 | 3,150 | 3,189 | 17.80 | 17.74 | 18.36 | 20.93 | 17.96 | 18.15 |
| 9 | 3,047 | 3,052 | 3,178 | 3,323 | 3,072 | 3,132 | 17.82 | 17.81 | 18.46 | 19.35 | 17.87 | 18.19 |
| 10 | 3,655 | 3,496 | 3,546 | 8,723 | 3,741 | 3,618 | 18.34 | 17.57 | 17.78 | 43.78 | 18.75 | 18.12 |
| 11 | 3,093 | 3,090 | 3,208 | 3,570 | 3,132 | 3,170 | 17.79 | 17.75 | 18.34 | 20.46 | 17.92 | 18.12 |
| 12 | 3,333 | 3,256 | 3,366 | 5,416 | 3,389 | 3,362 | 18.00 | 17.59 | 18.08 | 29.18 | 18.24 | 18.06 |
| 13 | 3,655 | 3,496 | 3,546 | 8,723 | 3,741 | 3,618 | 18.34 | 17.57 | 17.78 | 43.78 | 18.75 | 18.12 |
| 14 | 2,385 | 2,504 | 2,649 | 2,309 | 2,416 | 2,561 | 18.18 | 19.00 | 20.10 | 17.58 | 18.33 | 19.43 |
| 15 | 5,967 | 3,936 | 3,855 | 15,463 | 4,680 | 4,073 | 27.10 | 17.88 | 17.51 | 70.22 | 21.24 | 18.48 |
| 16 | 1,928 | 2,072 | 2,222 | 1,840 | 1,984 | 2,134 | 19.47 | 20.93 | 22.44 | 18.58 | 20.04 | 21.55 |
| 17 | 3,985 | 3,661 | 3,658 | 11,067 | 3,960 | 3,789 | 19.20 | 17.66 | 17.64 | 53.36 | 19.06 | 18.23 |
| 18 | 3,096 | 3,093 | 3,212 | 3,588 | 3,136 | 3,174 | 17.79 | 17.75 | 18.34 | 20.54 | 17.93 | 18.12 |
| 19 | 6,944 | 4,048 | 3,944 | 17,428 | 5,336 | 4,194 | 30.88 | 17.99 | 17.52 | 77.44 | 23.70 | 18.62 |
| 20 | 3,096 | 3,093 | 3,212 | 33,588 | 3,136 | 3,174 | 17.79 | 17.75 | 18.34 | 20.54 | 17.93 | 18.12 |
| 20-year average | 3,495 | 3,179 | 3,252 | 6,715 | 3,366 | 3,278 | 19.59 | 18.25 | 18.75 | 34.97 | 19.02 | 18.77 |

[a]Based on 65 percent packed fruit; average variation in daily receipts; use of operating rule 1 (2-shift operation, 16 hours per day); provision for on-site storage of both packed and field-run fruit and for the shipment of packed fruit to commercial storage (with penalty cost = $8.25 per 1,000 pounds) and field-run to commercial storage and return for packing (with penalty cost = $14 per 1,000 pounds).

The full range of capacity combinations considered, but not fully reported here, extended over packing capacities of 300,000 to 540,000 pounds per hour (increments = 60,000 pounds per hour) and over refrigeration capacities of 1,400 to 2,200 tons per hour (increments = 100 tons per hour). Actual computed minimum not shown.

Source: Calculated.

TABLE 20

Twenty-Year Average Total Season Cost of Packing and Precooling Fresh Pears in Relation to Variation in Packing and Refrigeration Capacities, Using Average Daily Receipts Pattern and Synthesized Variation in Annual Production
Lake County, California
(1972 Price Level)[a]

| Refrigeration capacity = $R_I$ | Total season cost with specified packing capacities 1,000 pounds per hour capacity = $V_t$ | | | | |
|---|---|---|---|---|---|
| | 300 | 360 | 420 | 480 | 540 |
| tons | 1,000 dollars | | | | |
| 2,500 | 3,246 | 3,186 | 3,188 | 3,226 | 3,282 |
| 2,400 | 3,301 | 3,186 | 3,183 | 3,217 | 3,272 |
| 2,300 | 3,376 | 3,188 | 3,180 | 3,209 | 3,262 |
| 2,200 | 3,495 | 3,193 | 3,179[b] | 3,203 | 3,252 |
| 2,100 | 3,692 | 3,205 | 3,180 | 3,199 | 3,244 |
| 2,000 | 3,933 | 3,241 | 3,184 | 3,198 | 3,238 |
| 1,900 | 4,250 | 3,302 | 3,192 | 3,199 | 3,235 |
| 1,800 | 4,602 | 3,380 | 3,205 | 3,205 | 3,236 |
| 1,700 | 5,016 | 3,499 | 3,223 | 3,214 | 3,239 |
| 1,600 | 5,483 | 3,696 | 3,248 | 3,228 | 3,247 |
| 1,500 | 6,037 | 3,942 | 3,295 | 3,247 | 3,260 |
| 1,400 | 6,715 | 4,257 | 3,366 | 3,270 | 3,278 |

[a]Based on 65 percent packed fruit; average variation in daily receipts; use of operating rule 1 (2-shift operation, 16 hours per day); provision for on-site storage of both packed and field-run fruit and for the shipment of packed fruit to commercial storage (with penalty cost = \$8.25 per 1,000 pounds) and field-run fruit to commercial storage and return for packing (with penalty cost = \$14 per 1,000 pounds).

[b]Cost minimum.

Source: Calculated.

TABLE 21

Total District Season Costs of Packing, Precooling, and Loading Fresh Pears (Excluding Assembly Costs) as Estimated With Selected Operating Models, Lake County, California (1972 Price Level)

| Analytical model[a] | Total District season cost |
| --- | --- |
| | 1,000 dollars |
| (1) Fixed (projected, 1985) total District volume, with uniform daily volume and 2-shift operation (with second-shift wage differential) throughout a 30-day season. $V_t$ = 465,300 pounds per hour; $R_I$ = maximum required. | 3,316[b] |
| (2) Fixed (projected, 1985) total District volume but with daily plant receipts variable within season; 2-shift operation with $V_t$ scaled to the plant size required under operating rule No. 1, assuming no storage of field-run fruit. Variations in $R_I$ simulated to determine value that would minimize total plant costs (Table 16). | 3,324[c] |
| (3) Same as model 2 but with simulation of variation in plant capacity to determine cost-minimizing size and provision of refrigeration capacity equal to maximum daily requirement (Table 16). | 3,254[d] |
| (4) Variable total District annual production, average within-season daily receipts pattern, operating rule 1 (2-shift operation). Selected values for packinghouse capacity, $V_t$, and refrigeration capacity, $R_I$; average of 20 seasons. | |
| $V_t$ = 300,000 pounds per hour; $R_I$ = 2,200 tons | 3,510 |
| $V_t$ = 300,000 pounds per hour; $R_I$ = 1,400 tons | 6,734 |
| $V_t$ = 420,000 pounds per hour; $R_I$ = 2,200 tons | 3,190 |
| $V_t$ = 420,000 pounds per hour; $R_I$ = 1,400 tons | 3,372 |
| $V_t$ = 540,000 pounds per hour; $R_I$ = 2,200 tons | 3,257 |
| $V_t$ = 540,000 pounds per hour; $R_I$ = 1,400 tons | 3,280 |

[a]$V_t$ = total packinghouse output (1,000 pounds per hour); $R_I$ = installed refrigeration capacity (tons of refrigeration).

[b]From Table 13, less assembly costs given in Table 10.

[c]$V_t$ = 551,000 pounds per hour; $R_I$ = 1,700 tons.

[d]$V_t$ = 440,000 pounds per hour; $R_I$ = 2,101 tons.

Source: Calculated.

In assessing the results of the foregoing, it should be noted that cost minimization in its simplest form may not be the controlling factor in the decision making of an individual firm or industry. For example, restrictions on plant capacity that require heavy diversions to commercial cold storage introduce more complex problems with respect to inventory control and the coordination of storage and processing operations. To an individual investor, an investment in plant capacity in excess of the cost–minimizing level, yet not substantially increasing total season costs, might be preferred so that operating and inventory procedures might be simplified. On the other hand, if capital funds are short or if reduction in long–term risk is desired, design capacities (and thus investment requirements) may be restricted below the values that would minimize long–run total costs. Thus, operating, control, and investment strategies not considered in this analysis may significantly influence plant design and the investment decisions of the individual firm or industry.

## Effect of Price Changes

The preceding results are based on 1972 prices. There has since been an extensive rise in price level; and this, along with the likelihood of further price changes, must be considered.

In the simplest terms—that is, as a rise (or fall) in price level with no change in relative prices among the various categories of inputs—no essential change in the findings beyond a corresponding rise in the level of estimated costs should be expected. Thus, if the price of each input factor were to increase by the same percentage, the level of estimated costs throughout the analysis would rise accordingly.[1] However, the indications as to optimum number of plants and as to cost effects of changes in relative capacities of packing and storage facilities and in daily delivery rates would remain essentially the same.

A more complex situation arises if changes in the prices of various inputs are uneven, that is, if there is a shift in relative prices for the various inputs. For example, a shift in relative prices of the alternative types of container considered would make more competitive the type experiencing the smaller price rise. An increase in labor wage rates relative to equipment prices would tend to favor mechanization. An increase in second–shift wage differential, with a given base wage rate, would be favorable to single–shift and overtime operation as compared with 2–shift operation.

Similarly, an increase in plant wage rates relative to cold storage equipment prices would tend to make packinghouse costs, where labor utilization is high, greater relative to storage costs. The effect of this would be to shift the optimum packinghouse–cold storage capacities relationship in the direction of greater cold storage capacity. On the

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[1] Of the major cost categories, the following approximate percentage increases (1972 to spring, 1975) have occurred: packinghouse labor, 18 percent; packinghouse and cold storage equipment, 15 to 20 percent; packaging materials, 40 percent; and electrical energy, 50 percent. Excluding packaging materials, the increase in plant costs, 1972 to 1975, approximates 18 percent.

other hand, an increase in electric power rates relative to other input prices would tip the optimum solution in the direction of relatively greater packinghouse capacity.[1] The converse of each of the above statements would also be true.

Over the period since 1959, price movements among the types of inputs used in pear packing and shipping operations reflect a fairly stable past structure of relative prices. Whether or not this will continue is at this point a matter of judgment. However, it may be reasonable to assume that price relationships among the wide range of suppliers of the required inputs will not soon change drastically. A possible exception is energy. But this would not affect a decision as to whether or not the major energy expense (for cold storage operation) should be incurred. The precooling operation is essential because pears are highly perishable. Higher energy costs would, as noted above, lead to lower storage capacities (and correspondingly higher packinghouse capacities) in the cost–minimizing solution. Even in this instance the relatively small variation in total District season costs over a wide range of packinghouse–storage capacity combinations shown in Table 21 suggests that considerable variation in energy prices could occur without seriously affecting the findings presented.

Finally, it should be recalled that expansion of present District season production to the total projected in 1985 will occur gradually. Reorganization of existing facilities and new investment in the expansion of plant capacity would occur at intervals during this period. Thus, with each new increment, planning decisions could be reviewed in the light of new information.

## XI. SUMMARY AND CONCLUSIONS

This report is an extension of a series of studies of costs and efficiency in local assembly, packing, and shipping operations for fresh pears. Its conceptual basis involves a production process occurring over a large area, a processing and storage activity concentrated in one or more plants located within the producing area, and a loading operation for shipment of the processed product to distant markets. The theoretical basis of the study involves both the theory of production and cost and location theory. Using estimated cost relationships for product assembly, packing, and storage, a modification of the linear programming transportation model is used to determine the number, size, and location of plants needed in the County such that total industry cost is minimized.

In the solution of an additional and closely related problem, the queuing problem is dealt with through simulation procedures. These are applied in the development of an analytical model for study of the optimum combination of processing and storage capacities under the conditions that hours of plant operation per day may be varied and that the raw product may either be processed immediately on receipt and prior to storage or be stored first as a field–run product and later withdrawn for packing and shipping.

[1] This change would occur because, in a plant of given capacity, the cold storage is a much heavier user of energy than the packinghouse.

**Empiric Setting and Underlying Cost Relationships**

The empiric analysis is focused on fresh pear packing operations in Lake County, California. This County is a major producing area for Bartlett pears averaging 46,000 tons annually over the period 1950–1971, 20 percent of total state output. The County presently is served by 10 separately owned packinghouses, 5 of which are grower–owned cooperatives; and the remaining 5 houses are small, privately owned, and primarily ranch–pack facilities. The five cooperative packinghouses, if operated at capacity through a 250–hour season, would together be capable of handling current total annual volume.

The major cost relationships in the analysis——product assembly, packing, precooling, and storage——were estimated by means of cost synthesis. The transportation cost function thus developed permits estimation of assembly costs as a function of quantity hauled per hour, length of haul, and type and capacity of equipment. From the packing cost function, total season costs may be computed in relation to type of shipping container; proportion of packed, cannery, and cull fruit; rate of output per hour; and length of operating season. Similarly, the cold storage cost function yields estimates of total season cost in relation to rate of loading of field fruit, total storage inventory, and length of operating season.

Both the packing and cold storage cost functions are linear with a positive constant term and so reflect economies of scale. Economies of scale in the packing operations are substantial over a relatively small range of plant size but are largely exhausted as plant capacity is expanded beyond 50,000 pounds per hour. Unit packing costs also decrease as hours of operation per season increase, but the rate of decrease becomes rather small as hours operated expand beyond 300 hours per season. Similar relationships are involved in the cold storage cost function although the constant term in this function is small, and the economies of scale are for practical purposes limited to the range of relatively small units.

Projections of pear production by location within Lake County in 1985 (when all existing orchard plantings, if retained, would be mature) are based on estimated pear acreage by individual land survey section derived from acreage and planting data of the California Crop and Livestock Reporting Service and estimates obtained from a sample of growers as to expected average yield per acre of mature trees. Current acreage and planting data, when adjusted for the method used by the Crop and Livestock Reporting Service in the initial recording of interplantings and replacement plantings, indicate the total land area in pears in Lake County to be approximately 6,000 acres. This is considerably below currently reported acreage. In a sample of growers, estimated normal yield per acre of mature trees approximated 16 tons.

The acreage and yield data indicate a projected average total annual output in the County, with all present plantings mature (1985), of 95,000 tons. This level of output is approximately twice the average of annual outputs over the period 1970–1972.

A transportation cost matrix derived from the estimated assembly cost function and a matrix of transportation distances are used to estimate costs per 1,000 pounds of fruit assembled from each origin to each of 15 locations within the County selected as potential plant sites.

With several key operational and cost–determining variables, the number of possible problem specifications for which optimizing solutions could be computed is very high. The specific solutions attempted are therefore limited initially to values of key variables selected as central to common operating ranges, with the results later subjected to limited sensitivity analysis.

**Optimum Number and Size of Plants**

The initial empiric solution involves a highly constrained situation in which the proportion of fruit packed for retail sale is fixed at 65 percent of the total volume of fruit received (with the remainder disposed of as cannery and cull fruit) and with all packed fruit shipped in the bulk–fill carton. Plant operating hours are set at 250 hours per season for a single–shift operation and 400 hours per season for a double–shift operation, with neither involving premium wage payments. The plants are assumed to operate at a uniform rate per hour throughout the season.

Under the conditions specified, total District season costs for processing the projected 1985 volume are minimized at approximately $3.4 million, the optimum solution involving a single plant of 465,300 pounds per hour capacity operating 2 shifts per day through a 400–hour season. However, the analysis shows that the number of plants operated can be increased substantially with only small diseconomies.

Under perfectly competitive market conditions, the long–run adjustment in the District to the single–plant, 2–shift operation would be the expected outcome. This, however, would require both drastic consolidation of existing plants and a complete shift to bulk–fill packing and 2–shift operation of the packinghouse. Commonly encountered "frictions" to adjustment might, however, obstruct the adjustment process. Such frictions include reluctance by existing firms to abandon existing brand identities, loyalties to existing personnel, uncertainty as to the availability of a work force amenable to night–shift operation, the possibility of the application of a premium wage requirement to night–shift work, and market resistance to a complete shift to the bulk–fill carton.

The cost effects of such institutional constraints on industry adjustment to the indicated optimum solution are examined in terms of the "opportunity cost" of not achieving the optimum. Thus, the opportunity cost of not shifting from the present output of equal proportions of packout in the standard box and the carton to a 100 percent carton pack is approximately $600,000 annually in terms of the projected 1985 annual volume. Operation on a single shift rather than a double shift per day basis would involve an opportunity cost of $230,000 annually. To operate at several plant sites rather than one would have only moderate effects on costs. For example, with 3 plants (one in each of the major producing areas), the estimated annual opportunity cost relative to the single–plant optimum would be only $22,000; with 5 plants (utilizing the locations of the existing 5 cooperatives), the annual opportunity cost is $72,600; while utilizing all 10 of the existing plant locations involves an opportunity cost of roughly $179,000 per year. The aggregate of the opportunity costs with no change from the status quo is in the neighborhood of $1,000,000 per year.

When alternative values for certain key variables are introduced, the level of costs and cost relationships among alternative models changes but without change in the indicated optimum organization (a single plant operating 2 shifts per day and a total of 400 hours per season). This organizational optimum holds despite the introduction of a 5 percent second–shift wage differential (although most of the cost "saving" indicated in the basic model disappears). Similarly, the same optimum solution as in the basic model continues as the industry cost–minimizing solution although at a lower level of total District cost if some or all of the existing plants (3, 5, or 10 plants) are retained and the long–run plant cost functions are adjusted to reflect continued use of existing facilities. Substantial shifts in total season volume (season volume set at 75, 90, and 110 percent of projected 1985 District total volume) result in significant changes in the level of total District season costs but with the industry cost–minimizing solution remaining as in the basic model, i.e., a single plant operating 2 shifts per day, 400 hours per season.

Despite the stability of the single–plant, double–shift optimum solution, a compelling case for extensive consolidation of existing plants is not established. The most easily achieved element of the optimum solution—a shift to a 100 percent carton pack, market conditions permitting—could be introduced without any consolidation of existing facilities. Similarly, any marketing advantages obtained through the consolidation of sales activities in the merging of existing plants could be achieved with no—or only partial—consolidation. Moreover, the retention of existing major facilities would accomplish most of the economies of plant consolidation but would reduce investment requirements for new facilities, as compared with the long–run optimum solution, and so might be an attractive suboptimal solution from the standpoint of limiting investment risks and the demand for new capital.

## Effects of Variation in Daily Plant Receipts and Annual Production Volume

The initial optimizing analysis, based on the assumption of a constant rate of demand for productive capacity both within and among seasons, is extended to the more realistic situations of variability in the daily receipts pattern within a given season and variability in total District volume of pear production among seasons. Under such circumstances, depending on the plant capacity provided in relation to the level of season total volume and daily plant receipts, there may be periods in which the demand for facilities is (1) excessive such that a waiting line or "queue" is formed or (2) so slight relative to installed capacity as to result in idle facility time. Consideration also is given to the possibility that adjustment of total plant capacity—so that receipts on peak days are stored field–run for later processing—may be economical; also to similar possibilities in the manipulation of field–run storage volume through long–run shifts in relative capacities of the packing and cold storage capacities.

In this phase of the study, three packinghouse operating models are considered: (1) 2–shift, 16–hour operation per day; (2) 1–shift, 8–hour operation per day; and (3) 1–shift operation with up to 2 hours of overtime—total, 10 hours—operation per day. The analytical model involves use of the concept of "penalty fruit," which is defined as the portion of a given day's receipts that cannot be processed normally because of insufficient packing or cold storage capacity. "Penalty costs" associated with such penalty fruit then become a part of estimated total season cost with a given operating situation. Simulation analysis—utilizing previously developed packing and cold storage cost functions, sample data as to within–season variation in daily receipts, and a synthesis of year–to–year variation in season total volume—is applied in an attempt to determine design capacities for the packing and cold storage facilities that would minimize total season costs under conditions of variation in daily plant receipts and total annual volume.

Through a succession of relatively simple simulations, a basis is established for selecting operating model 1 (2–shift, 16–hour operation per day) as the one through which the question of optimum (cost–minimizing) plant design capacities should be explored. Through further simulation analyses, economies are shown to result if design refrigeration and packing capacities are constrained to a level below maximum daily requirements, and the packing capacity design rate is established at a level below that required to pack the projected normal season volume of 186,122,000 pounds of fruit under the assumption of a uniform daily volume of receipts. The degree of "design constraint," under the operating conditions specified, involves a reduction in refrigeration design capacity of about 20 percent below maximum daily requirements and a design packing capacity approximately 5 percent below that indicated by solutions based on a projected normal season volume and the assumption of a uniform daily volume of receipts.

### Stability of Empiric Results

Throughout, the optimizing analysis involves simplifying assumptions as to operating conditions (e.g., specification of packed fruit as 65 percent of total fruit run and 100 percent packout in volume–filled cartons rather than a mix of carton and place–packed standard boxes). However, sensitivity analyses indicate that substantial shifts in the values selected for such variables could occur without changing the general nature of the findings, although changes in values assigned to key values may modify substantially the overall level of estimated costs.

It is also noteworthy that, with the exception of a shift from the standard box to carton packing, a rather wide range of options as to operating procedure and design standards can be exercised without incurring major diseconomies. Since some of the possible options may involve substantial operating inconvenience or unincluded costs (e.g., increased inventory management expenses under some operating conditions), practical managerial decisions may reflect choices other than those specified purely in terms of cost minimization.

In sensitivity tests of the single–plant optimum solution as to size and number of plants made under the assumption of uniform daily receipts of field fruit, it was demonstrated that a substantially larger number of plants could be operated in the District without serious diseconomies. A similar stability should apply to the relationships developed in the context of variable daily receipts and year–to–year variation in total season volume.

While stability in the empiric findings enhances their utility as a guide to decision making by individual firms or the industry, such decisions may as well be influenced by other factors. For example, rather than intensify problems in inventory control and the coordination of plant operations, some firms might choose plant capacities larger than those required for cost minimization. Or a shortage of capital funds or an aversion to long–term risk might induce the individual firm or industry to restrict design capacity even though total season costs are on the average higher than optimum.

### The Effect of Price Changes

The empiric analysis is based on 1972 prices, and there has since been a continuing inflation such that plant costs (exclusive of packing materials) in the 1975 season are estimated to be 18 percent higher than in 1972. (Over the three–year period, packaging materials have increased roughly 40 percent.) Despite the price changes, the general indications of the empiric analysis still hold.

**Cost Minimization in Relation to Market Performance**

The extent to which market performance might be affected by increasing concentration of plant facilities, in the optimum solution leading to a single plant and a situation of local monopoly in this county, is not dealt with in this study. However, the alternative solutions considered do provide indications as to the opportunity costs of various suboptimal solutions against which might be weighed the risk to growers of discriminatory practices that could arise with increased concentration of processing firms. With the present dominance of the cooperative firm in the area, monopsonistic practices directed by a single cooperative at growers as a whole (without discrimination among individual growers) would be circular in their effects since any benefits to the cooperative would eventually be shared with the cooperating growers.

On the selling side, cannery fruit prices presently are determined through industrywide bargaining procedures so that consolidation of packing facilities and firms would produce no new effects. Sales operations on the retail market might, however, be more subject to management in a consolidated sales activity as compared with present arrangements. An obvious means made more feasible through consolidation of sales effort would be advertising aimed at enhancing product demand and price. However, such a District advertising campaign would presumably only modify or substitute for an existing industrywide effort now supported through the California Tree Fruit Agreement; and so the net effect of change in local industry structure might be presumed to have little potential impact. Modified schedules of delivery to markets aimed at restricting daily supplies in the expectation of increasing prices would be constrained by the relatively short storage life of Bartlett pears and by the fact that pears from the Pacific Northwest begin reaching the market soon after the close of the Lake County harvest season. This would inhibit prolongation of the marketing season for Lake County Bartletts. While such effects remain to be measured, the plausible hypothesis might be advanced that a "monopoly" created through consolidation of fresh market sales activities within the District would not have a price effect seriously adverse to consumers.

Based on the above, it appears that creating a local monopoly through adoption of the optimum solution indicated in the empirical analysis of this study would have little practical effect on market performance. Nonetheless, the market–performance implications in optimizing models, such as developed in this study, remain of great theoretical importance and as a constraint on the implementation of results obtained in application of the model.

## APPENDIX A

### List of Selected Variables in the Empirical Analysis

$A$ = storage floor space (1,000 square feet)

$A_v$ = fixed cost per season for a packinghouse with hourly capacity $V_t$ (dollars)

$AFC_r$ = annual fixed cost for refrigeration equipment (dollars)

$AFC_s$ = annual fixed cost for the storage building (dollars)

$B_{1v}$ = operating cost per hour of straight–time operation for a packinghouse with hourly capacity $V_t$ (dollars per hour)

$B_{2v}$ = operating cost per hour of overtime operation for a packinghouse with hourly capacity $V_t$ (dollars per hour)

$E(TPC)$ = expected total season plant cost

$H_j$ = hours of packinghouse operation on the $j$th day

$H$ = hours of packinghouse operation per season

$H_s$ = hours of storage operation per season

$H_{ot}$ = hours of packinghouse operation per season at overtime wage rates

$H_{st}$ = hours of packinghouse operation per season at straight–time wage rates

$HVC_r$ = variable cost for refrigeration equipment per hour of storage operation (dollars)

$H_{js}$ = hours of storage operation on the $j$th day = 24

$I_r$ = total investment cost of installed refrigeration equipment (dollars)

$I_b$ = total investment cost of the cold storage building (dollars)

$K$ = number of days during the season on which no fruit was packed

$k$ = operating rule which specifies company policy with respect to overtime operations and storage of field–run fruit

$L$ = storage loading rate (1,000 pounds of fruit per day)

$M$ = cost per ton of penalty fruit (dollars)

$N$ = number of calendar days in the packing season

$n$ = number of days of packinghouse operation per season

$P_p$ = proportion of fruit packed

$P$ = expected receipts distribution

$Q$ = proportion of total fruit packed using place–pack procedures

$R_I$ = installed refrigeration capacity (tons of refrigeration)

$R_j$ = refrigeration capacity required on the *j*th day (tons of refrigeration)

$R$ = refrigeration load (tons of refrigeration)

$S$ = storage capacity defined in terms of the vector [R, A] which specifies refrigeration capacity in tons of refrigeration and storage space in 1,000 square feet of floor space

$SC_1$ = precool storage capacity (1,000 pounds of fruit)

$SC_2$ = storage capacity in excess of precooling requirements (1,000 pounds of fruit)

$SVC_s$ = total variable storage cost per season (dollars)

TC = total season assembly and plant costs (dollars)

TDPC = total District season plant cost (dollars)

TPC = total season plant cost (dollars)

TSSC = total season storage costs (dollars)

TSPC = total season packinghouse cost (dollars)

TSVSC = total season variable storage costs (dollars)

$V$ = total season volume (1,000 pounds)

$V_{dj}$ = rate of diversion of field–run fruit to cold storage on the *j*th day (1,000 pounds per hour)

$V_{pj}$ = packing rate on the *j*th day (1,000 pounds per hour)

$V_{wj}$ = rate of withdrawal of diverted fruit for packing on the *j*th day (1,000 pounds per hour)

$V_p^B$ = volume of fruit bulk–filled (1,000 pounds per hour)

$V_p^P$ = volume of fruit place–packed (1,000 pounds per hour)

$V_c$ = volume of cannery and cull fruit run (1,000 pounds per hour)

$V_p$ = volume of fruit packed for fresh shipment (1,000 pounds per hour)

$V_t$ = total packinghouse output (1,000 pounds per hour)

# APPENDIX B

## Production Standards, Equipment Cost Data, and Basic Syntheses of Packinghouse Labor and Equipment Requirements

Cost syntheses presented in summary form in Section IV involve the application of the following production standards and equipment cost data as presented in Appendix Tables B–1 to B–6.

### Cannery and Cull Fruit Packaging

Total man–hours required for packaging cannery and cull fruit are 0.08 per 1,000 pounds of fruit with a minimum of one man required for the job. Additional workers required in this stage are hired in increments of one; that is, no splitting of duties between this stage and any other stage is assumed. Labor cost per worker is $2.51 per hour including a 13.2 percent allowance for fringe benefits.

Equipment requirements are based upon production standards in Stollsteimer (1961). Annual fixed equipment cost is based upon standardized annual charges for depreciation, interest, repairs, taxes, and insurance (Appendix Table B–6). A 1/2 horsepower motor is required for each conveyor used in this stage. Electrical power cost is estimated at 3 cents per hour for each motor horsepower, while repair cost is estimated at 1/2 percent of replacement cost per 100 hours of operation.

### In–Plant Transportation

Forklift trucks are the major items of equipment required for in–plant transportation. However, for the purpose of analysis, bins used for assembling fruit from orchard to packinghouse are included in the cost analysis of this stage along with the pallets used for storing packed fruit.

Hours of forklift operation in packinghouse operations are based upon production standards in Stollsteimer (1961). Each packinghouse is assumed to own at least one butane–powered truck but not less than 10 percent of its maximum truck requirement. Owned trucks are all butane powered. All other trucks are rented for a period of 1½ months which includes any rental before and after the plant operating season. If the number of packinghouse–owned, butane–powered trucks is not sufficient for use in transporting packed fruit to cold storage, electric–powered fork trucks are rented for this purpose. For all other uses, gasoline–powered trucks are used. Annual fixed equipment cost for owned fork trucks is based upon standardized annual charges for depreciation, interest, repairs, taxes, and insurance of 16.8 percent of replacement cost. Monthly rental rate for fork trucks is 5 percent of purchase price. Variable cost of operation for butane–powered trucks is estimated as 69 cents per hour; for gasoline–powered trucks, 22 cents per hour. Rented electric–powered trucks are estimated not to have any variable operating cost payable by the packinghouse.

One operator is required for each forklift truck used. Operator labor cost is $2.74 per hour including a 13.2 percent allowance for fringe benefits.

Thirty bins per 1,000 pounds of fruit received per hour are estimated to be required for packinghouse operation (cost data are given in Appendix Table B–6).

Pallet requirements are estimated as a function of packed–fruit output rate and the number of days packed fruit is stored. Each pallet can hold 48 standard boxes or 54 cartons. Based on storing packed fruit for three days, the number of pallets required is obtained as:

*Standard boxes:* $N = 10.2\ V_p$

*Cartons:* $N = 12.0\ V_p$

where N is number of pallets required and $V_p$ is volume of fruit packed for fresh shipment in 1,000 pounds per hour (cost data are given in Appendix Table B–6).

## Truck Loading

All packed fruit is assumed to be loaded in trucks for shipment. Labor requirements for truck loading are based upon production standards in Stollsteimer (1961). Labor cost for the loading operation is $3.01 per hour for each worker including a 13.2 percent allowance for fringe benefits.

## Miscellaneous Equipment Costs

Miscellaneous equipment costs are estimated by adjusting the 1959 miscellaneous equipment cost equation (Stollsteimer, 1961) by an index number of miscellaneous equipment with 1959 as the base. The value of this index based on the first six months of 1972 is 131.45. The 1972 replacement cost for miscellaneous equipment is estimated as

$$MERC = 1{,}643 + 427\ V_t$$

where MERC is 1972 miscellaneous equipment replacement cost and $V_t$ is total packinghouse output in 1,000 pounds per hour. Annual fixed costs for miscellaneous equipment are estimated as 15.87 percent of replacement cost.

**Administrative Expense**

The 1972 administrative expense was obtained by multiplying the 1959 administrative expense equation (Stollsteimer, 1961) by an index number calculated using 1959 and 1972 in–plant wage rates for several job classifications (Appendix Table B–4). The 1972 administrative cost equation is obtained as

$$AE = 1{,}003 + 369 V_t$$

where AE is 1972 administrative expense and $V_t$ is total packinghouse output in 1,000 pounds per hour.

**Building Cost**

Building space requirements for pear packing operations are based upon standards presented in French, Sammet, and Bressler (1956) and Stollsteimer (1961). Building costs were estimated using a procedure developed by Sammet (1958). Using this production standard and cost information, a building investment cost equation was obtained as

$$I = 44.98148 + 1.428323 V_p + 1.367327 V_t$$

where

$I$ = building investment

$V_p$ = volume of fruit packed for fresh shipment (1,000 pounds per hour)

and

$V_t$ = total packinghouse output (1,000 pounds per hour).

Average annual fixed cost for the building was estimated as 9 percent of investment cost itemized as follows: depreciation, 2.5; repairs, 1.8; interest, 3.1; insurance, 0.6; and taxes, 1.0 percent.

APPENDIX TABLE B-1

Estimated Labor and Equipment Requirements in the Grading Stage of Pear Packinghouses
by Rate of Output and Percentage of Fruit Fresh Packed
Lake County, California, 1972[a]

| Total packing-house output rate | Percentage of fruit fresh packed | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 percent | | | 60 percent | | | 70 percent | | | 80 percent | | | 90 percent | | |
| | Graders required[b] | Grading tables required[c] | | Graders required[b] | Grading tables required[c] | | Graders required[b] | Grading tables required[c] | | Graders required[b] | Grading tables required[c] | | Graders required[b] | Grading tables required[c] | |
| 1,000 pounds per hour | number | | length in feet | number | | length in feet | number | | length in feet | number | | length in feet | number | | length in feet |
| 10 | 10 | 1 | 17.5 | 10 | 1 | 17.5 | 10 | 1 | 17.5 | 10 | 1 | 17.5 | 9 | 1 | 17.5 |
| 20 | 12 | 1 | 21.0 | 12 | 1 | 21.0 | 12 | 1 | 21.0 | 12 | 1 | 21.0 | 12 | 1 | 21.0 |
| 30 | 21 | 2 | 21.0 | 21 | 2 | 21.0 | 21 | 2 | 21.0 | 15 | 2 | 14.0 | 14 | 2 | 14.0 |
| 40 | 23 | 2 | 21.0 | 23 | 2 | 21.0 | 23 | 2 | 21.0 | 23 | 2 | 21.0 | 23 | 2 | 21.0 |
| 50 | 28 | 3 | 17.5 | 28 | 3 | 17.5 | 26 | 3 | 17.5 | 26 | 3 | 17.5 | 26 | 3 | 17.5 |
| 60 | 35 | 3 | 21.0 | 35 | 3 | 21.0 | 35 | 3 | 21.0 | 28 | 3 | 17.5 | 28 | 3 | 17.5 |
| 70 | 38 | 4 | 17.5 | 38 | 4 | 17.5 | 38 | 4 | 17.5 | 38 | 4 | 17.5 | 38 | 4 | 17.5 |
| 80 | 46 | 4 | 21.0 | 42 | 4 | 21.0 | 42 | 4 | 21.0 | 42 | 4 | 21.0 | 38 | 4 | 17.5 |
| 90 | 51 | 5 | 21.0 | 51 | 5 | 21.0 | 51 | 5 | 21.0 | 51 | 5 | 21.0 | 42 | 4 | 21.0 |
| 100 | 56 | 5 | 21.0 | 56 | 5 | 21.0 | 56 | 5 | 21.0 | 51 | 5 | 21.0 | 51 | 5 | 21.0 |
| 110 | 64 | 6 | 21.0 | 64 | 6 | 21.0 | 56 | 5 | 21.0 | 56 | 5 | 21.0 | 56 | 5 | 21.0 |
| 120 | 69 | 6 | 21.0 | 64 | 6 | 21.0 | 64 | 6 | 21.0 | 64 | 6 | 21.0 | 56 | 5 | 21.0 |

[a]Labor and equipment requirements based upon production standards in French, Sammet, and Bressler (1956, pp. 613-619) and Stollsteimer (1961, pp. 81-86). However, observation of grading practices currently used by plants in Lake County revealed that some changes had occurred since the earlier studies. The effect of the changed practices is to increase the number of graders required. In this study the number of graders required is estimated to be 15 percent greater than indicated by the established production standards. For estimation purposes the earlier standards are used, and the estimated number of graders is increased by 15 percent. Equipment requirements are based upon the number of graders required.

[b]Includes one head grader for each grading table. Hourly labor cost for head graders = $2.65 based on a wage rate of $2.245 per hour and a 13.2 percent allowance for fringe benefits. Hourly labor cost for other sorters = $2.54 based on a wage rate of $2.245 and a 13.2 percent allowance for fringe benefits.

[c]Annual fixed equipment cost is based upon estimated annual charges for depreciation, interest, repairs, taxes, and insurance of 15.87 percent of replacement cost (see Appendix Table B-6 for list of equipment replacement costs and annual fixed charges). Variable equipment cost includes repairs and electric power cost. Repairs are estimated at 0.5 percent of replacement cost per 100 hours of operation. Electric power is estimated at 3.0 cents per motor horsepower. Using these rates, hourly variable costs are as follows: 14-foot table, 11 cents; 17.5-foot table, 14 cents; and 21-foot table, 16 cents.

Source: Calculated.

APPENDIX TABLE B-2

Estimated Labor and Equipment Requirements[a] in the Packing Stage[b] of Bulk-Fill Pear Packing Plants, by Volume of Fruit Packed
Lake County, California, 1972

| Volume packed | | Operation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Packing and container supply | | | Check weigh | Container sealing | | | Container setoff | |
| | | Filling machines[d] | Workers[c] Fold cartons | Workers[c] Tend machines | Workers[e] | Sealing machines[f] | Machine capacity[g] | Workers[h] | Work stations | Workers[i] |
| 1,000 pounds per hour | cartons per hour[j] | number | | | | | cartons per hour | number | | |
| 10 | 270 | 1 | 2 | 1 | 1 | 1 | 300 | 1 | 1 | 1 |
| 20 | 540 | 1 | 3 | 2 | 1 | 1 | 800 | 2 | 1 | 2 |
| 30 | 811 | 2 | 4 | 4 | 2 | 1 | 1,000 | 2 | 2 | 4 |
| 40 | 1,081 | 2 | 6 | 4 | 2 | 1 | 1,200 | 3 | 2 | 4 |
| 50 | 1,351 | 2 | 8 | 6 | 4 | 2 | 800 | 3 | 2 | 6 |
| 60 | 1,621 | 3 | 9 | 6 | 3 | 2 | 1- 800<br>1-1,000 | 4 | 3 | 6 |
| 70 | 1,892 | 3 | 12 | 9 | 6 | 2 | 1- 800<br>1-1,000 | 4 | 3 | 9 |
| 80 | 2,162 | 3 | 12 | 9 | 6 | 2 | 1-1,000<br>1-1,200 | 5 | 3 | 9 |
| 90 | 2,432 | 4 | 12 | 8 | 4 | 4 | 800 | 6 | 4 | 12 |
| 100 | 2,703 | 4 | 16 | 12 | 8 | 4 | 800 | 6 | 4 | 12 |
| 110 | 2,973 | 4 | 16 | 12 | 8 | 4 | 800 | 6 | 4 | 12 |
| 120 | 3,243 | 5 | 20 | 15 | 10 | 5 | 800 | 10 | 5 | 15 |

(Continued on next page.)

APPENDIX TABLE B-2--continued.

[a]Based upon production standards in Stollsteimer (1961).

[b]In this analysis the packing stage is defined to include not only the filling of containers but also a number of other plant operations which relate to the packing operation. These additional operations include container supply, check weigh, container sealing, and container setoff. For a description of these operations, see Stollsteimer (1961).

[c]Labor cost per worker = $2.51 per hour including a 13.2 percent allowance for fringe benefits.

[d]Annual fixed cost for each bulk-fill machine is based upon standardized annual charges for depreciation, interest, repairs, taxes, and insurance of 13.37 percent of replacement cost (see Appendix Table B-6 for list of equipment replacement costs and annual fixed charges). Variable equipment cost includes repairs and electric power cost. Hourly variable equipment cost for each bulk-fill machine is estimated at $1.92.

[e]Annual fixed cost for equipment required for each check weigher is based upon standardized annual charges for depreciation, interest, repairs, taxes, and insurance (see Appendix Table B-6 for list of equipment replacement costs and annual fixed charges). Labor cost per worker = $2.51 per hour including a 13.2 percent allowance for fringe benefits.

[f]Annual fixed cost for each sealing machine is based upon standardized annual charges for depreciation, interest, repairs, taxes, and insurance (see Appendix Table B-6 for list of equipment replacement costs and annual fixed charges). In addition to the sealing machine, a stapling machine is also required for the container sealing operation (see Appendix Table B-6 for replacement cost and annual fixed charges). Hourly variable equipment cost for each stapling machine is estimated at 20 cents.

[g]Hourly variable equipment costs for sealing machines were estimated as:

| Machine capacity (cartons per hour) | Variable cost (cents per hour) |
|---|---|
| 300 | 40 |
| 800 | 48 |
| 1,000 | 50 |
| 1,200 | 54 |

[h]Labor cost per worker = $2.91 per hour including a 13.2 percent allowance for fringe benefits.

[i]Labor cost per worker = $2.74 per hour including a 13.2 percent allowance for fringe benefits.

[j]Based on a net weight of 37 pounds per carton. Estimated materials cost for each carton = 52.2 cents.

Source: Calculated.

APPENDIX TABLE B-3

Estimated Labor Requirements and Number of Work Stations in the Packing Stage[a] of Place-Pack Pear Packing Plants, by Volume of Fruit Packed Lake County, California, 1972[b]

| Volume packed | | Operation | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Packing | | Container assembly and supply | | | | | | | Container closure | | | | | | Container setoff | |
| | | | | Box making | | | Placing pads and liners | | | | Work stations | Workers | | | | | | |
| | | | | Work station[g] | Workers | | Work stations[i] | Workers[c] | | | | Tally[j] | Stamp[j] | Check-weigh[j] | Close container[d] | | Work stations | Work-ers[k] |
| 1,000 pounds per hour | standard boxes per hour[1] | Lines[e] | Pack-ers[f] | | Machine opera-tors[h] | Help-ers[h] | | Pads and liners | Poly-ethlyene bag | Transfer empty boxes to con-veyor | | | | | Machine opera-tor | Helper | | |
| | | number | | | | | | | | | | | | | | | | |
| 10 | 204 | 1 | 16 | 1 | 1 | 0 | 1 | 1 | | 1 | 1 | 1 | 1 | | 1 | 0 | 1 | 2 |
| 20 | 408 | 2 | 32 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 3 |
| 30 | 612 | 3 | 48 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 5 |
| 40 | 816 | 4 | 63 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 0 | 1 | 6 |
| 50 | 1,020 | 5 | 79 | 2 | 2 | 2 | 2 | 3 | 4 | 3 | 2 | 2 | 2 | 2 | 2 | 0 | 2 | 7 |
| 60 | 1,224 | 5 | 95 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 2 | 2 | 4 | 2 | 2 | 2 | 2 | 9 |
| 70 | 1,429 | 6 | 110 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 2 | 2 | 4 | 4 | 2 | 0 | 2 | 10 |
| 80 | 1,633 | 7 | 126 | 3 | 3 | 3 | 3 | 6 | 6 | 3 | 2 | 3 | 4 | 4 | 2 | 0 | 2 | 11 |
| 90 | 1,837 | 8 | 142 | 4 | 4 | 4 | 4 | 8 | 4 | 4 | 2 | 3 | 4 | 4 | 2 | 0 | 2 | 13 |
| 100 | 2,041 | 9 | 157 | 4 | 4 | 4 | 4 | 8 | 8 | 4 | 3 | 3 | 6 | 3 | 3 | 3 | 3 | 14 |
| 110 | 2,245 | 10 | 173 | 4 | 4 | 4 | 4 | 8 | 8 | 4 | 3 | 4 | 6 | 6 | 3 | 0 | 3 | 15 |
| 120 | 2,449 | 10 | 189 | 5 | 5 | 5 | 5 | 10 | 5 | 5 | 3 | 4 | 6 | 6 | 3 | 0 | 3 | 17 |

(Continued on next page.)

APPENDIX TABLE B-3--continued.

[a]In this analysis the packing stage is defined to include not only the actual placing of fruit in shipping containers but also a number of other plant operations which relate to the packing operation. The additional operations include container assembly and supply, container closure, and container setoff. For a description of these operations, see French, Sammet, and Bressler (1956) and Stollsteimer (1961).

[b]Except as noted, labor and equipment requirements are based upon production standards in French, Sammet, and Bressler (1956) and Stollsteimer (1961).

[c]Placing pads and liners labor cost = $2.51 per hour for each worker including a 13.2 percent allowance for fringe benefits.

[d]A lidding machine is required for closing containers. The number of such machines required is given by the number of work stations in the container closure operation. Annual fixed equipment cost for each machine is based upon standardized annual charges for depreciation, interest, repairs, taxes, and insurance of 13.37 percent of replacement cost (see Appendix Table B-6 for list of equipment replacement costs and annual fixed charges). Machine operator labor cost = $2.91 per hour including allowance for fringe benefits, while labor cost for each machine operator helper = $2.51 per hour including fringe benefit allowance.

[e]Annual fixed equipment cost for each packing line is based upon standardized annual charges for depreciation, interest, repairs, taxes, and insurance of 13.37 percent of replacement cost (see Appendix Table B-6 for list of equipment replacement costs and annual fixed charges). Variable equipment cost includes repairs and electric power cost. Repairs are estimated at 0.5 percent of replacement cost per 100 hours of operation. Electric power is estimated at 3.0 cents per motor horsepower. Using these rates, hourly variable costs per packing line total 73 cents.

[f]Packing labor cost = 28.3 cents per box based on a cost rate of 25 cents per box and including a 13.2 percent allowance for fringe benefits.

[g]One box-making machine required per work station. Annual fixed equipment cost for each machine is based upon standardized annual charges for depreciation, interest, repairs, taxes, and insurance of 13.37 percent of replacement cost (see Appendix Table B-6 for list of equipment replacement costs and annual fixed charges). Hourly variable costs for each box-making machine are estimated at 51 cents.

[h]Box-making labor cost = $2.15 per 100 boxes based on a cost rate of $1.90 per 100 boxes and including a 13.2 percent allowance for fringe benefits.

[i]Equipment required for placing pads and liners consists of a conveyor system for distributing boxes to packing lines. Annual fixed equipment cost is based upon standardized annual charges for depreciation, interest repairs, taxes, and insurance of 13.37 percent of replacement cost (see Appendix Table B-6 for list of equipment replacement costs and annual fixed charges). Variable equipment cost per hour is estimated at 0.5 percent of replacement cost per 100 hours of operation plus 1.5 cents per packing line in the packinghouse.

[j]Annual fixed cost for equipment required for each worker is based upon standardized annual charges for depreciation, interest, repairs, taxes, and insurance (see Appendix Table B-6 for list of equipment replacement costs and annual fixed charges). Labor cost per worker = $2.51 per hour including a 13.2 percent allowance for fringe benefits.

[k]Labor cost per worker = $2.74 per hour including a 13.2 percent allowance for fringe benefits.

[l]Based on a net weight of 49 pounds per standard box. Estimated materials cost for each standard box = 91 cents including cost of applying labels.

Source: Calculated.

APPENDIX TABLE B-4

Direct Supervision and Miscellaneous Labor Requirements and Costs in Pear Packinghouses, by Packinghouse Output Rate Lake County, California, 1972

| Job category | Packinghouse output rate | Labor required per 8 hours of packinghouse operation[a] | Labor cost per hour of packinghouse operation[b] |
|---|---|---|---|
| | 1,000 pounds per hour | hours | dollars per hour |
| Direct supervision | 0.0- 10.0 | 8.0 | 5.44 |
| | 10.1- 35.0 | 16.0 | 10.88 |
| | 35.1- 60.0 | 24.0 | 16.32 |
| | 60.1- 90.0 | 32.0 | 21.76 |
| | 90.1-120.0 | 40.0 | 27.19 |
| Seasonal office clerks | 0.0- 60.0 | 16.0 | 4.76 |
| | 60.1-120.0 | 24.0 | 7.70 |
| Nightmen (janitors and watchmen) | 0.0- 60.0 | 10.0 | 3.02 |
| | 60.1-120.0 | 20.0 | 6.04 |
| Weighmasters | 0.0- 20.0 | 2.5 | 0.80 |
| | 20.1- 40.0 | 5.0 | 1.60 |
| | 40.1- 60.0 | 7.5 | 2.41 |
| | 60.1- 80.0 | 10.0 | 3.21 |
| | 80.1-100.0 | 12.5 | 4.01 |
| | 100.1-120.0 | 15.0 | 4.81 |
| Utility men | 0.0- 20.0 | 8.0 | 2.51 |
| | 20.1- 50.0 | 16.0 | 5.02 |
| | 50.1- 80.0 | 24.0 | 7.53 |
| | 80.1-110.0 | 32.0 | 10.04 |
| | 110.1-140.0 | 40.0 | 12.55 |

[a]Labor requirements are based upon production standards in Stollsteimer (1961).

[b]The 1972 labor cost was obtained by adjusting the 1959 labor cost by an index constructed using a number of in-plant job classifications. These classifications included sorting, packing, container setoff, and in-plant transportation labor. Using the 1959 and 1972 wage rates for these job classifications, an index of 160.44 was obtained. The 1959 labor cost rate for all direct supervision and miscellaneous labor job categories was multiplied by this index to calculate the 1972 labor costs.

Source: Calculated.

APPENDIX TABLE B-5

Estimated Labor and Equipment Requirements and Costs for Inspecting Incoming Fruit in Pear Packinghouses Lake County, California, 1972[a]

| Item | Packinghouse volume less than 20,000 pounds per hour | Packinghouse volume greater than 20,000 pounds per hour |
|---|---|---|
| Installed cost[b] | | |
| Grading table | $224 | $1,024 |
| Scales | $627 | $ 627 |
| Annual fixed equipment cost[c] | $114 | $ 221 |
| Labor requirements per 1,000 pounds of fruit sample graded (man-hours)[d] | 1.9 | 1.9 |
| Hourly labor cost for inspection labor[e] | $2.63 | $ 2.63 |

[a]Labor and equipment requirements based upon production standards in French, Sammet, and Bressler (1956, pp. 657-659) and Stollsteimer (1961, pp. 117-119).

[b]Obtained by adjusting the 1959 installed cost reported in Stollsteimer (1961) by appropriate U. S. Bureau of Labor Statistics wholesale price indices using a 1959 base. The grading-table installed cost was adjusted by the Agricultural Machinery and Equipment Wholesale Price Index, while the scales installed cost was adjusted by the Portable Dial Scale Wholesale Price Index (see footnote, Appendix Table B-6 for values of the indices).

[c]Based upon estimated annual charges for depreciation, interest, repairs, taxes, and insurance of 13.37 percent of replacement costs.

[d]For cost calculations it is assumed that 5 percent of the fruit delivered to the packinghouse is sample graded.

[e]Based on a wage rate of $2.32 per hour and including a 13.2 percent allowance for fringe benefits.

Source: Calculated.

APPENDIX TABLE B-6

Installed Costs, Estimated Use Life, and Annual Fixed Charges for Equipment Items Used in Fresh Pear Packinghouses, Lake County, California, 1972

| Item | Installed cost[a] | Estimated use life | Annual fixed charges[b] |
|---|---|---|---|
| | dollars | years | dollars |
| Bin dumper | 3,648 | 15 | 488 |
| Dryer | 3,214 | 15 | 430 |
| Dump tank | 1,442 | 15 | 193 |
| Sorting table | | | |
| 14 feet | 1,514 | 15 | 240[c] |
| 17.5 feet | 1,846 | 15 | 293[c] |
| 21 feet | 1,965 | 15 | 312[c] |
| 28 feet | 4,326 | 15 | 687[c] |
| Place-pack packing line, complete | 12,177[d] | 15 | 1,628 |
| Box mailing machine | 8,245 | 15 | 1,102 |
| Bulk-fill packing unit, complete | 34,758 | 15 | 4,646 |
| Carton sealer | | | |
| 300 cases per hour | 7,862 | 15 | 1,051 |
| 800 cases per hour | 9,217 | 15 | 1,232 |
| 1,000 cases per hour | 9,754 | 15 | 1,304 |
| 1,200 cases per hour | 10,296 | 15 | 1,377 |
| Carton stapler | 4,038 | 15 | 540 |
| Lidder | 7,174 | 15 | 960 |
| Scales | | | |
| In-line 100-pound dial reading | 627[e] | 15 | 84 |
| Stamps | 19[f] | 15 | 3 |
| Stamp desk | 14[g] | 15 | 2 |
| Bins | 19[h] | 10 | 3 |
| Forklift trucks | | | |
| Butane | 9,450[i] | 10 | 1,588 |
| Gasoline | 8,400[i] | 10 | 630[j] |
| Electric | 12,600[i] | 10 | 945[j] |
| Conveyor | | | |
| Belt | $355 + 22L + 0.59WL$[k,l] | 15 | $56 + 3.49L + 0.09WL$[c] |
| Monorail | $704 + 9.19L$[k,l] | 15 | $112 + 1.46L$[c] |
| Pallets (quantities) | | | |
| 1-263 | 5.09 each[h] | 10 | 0.86 |
| 264 | 4.83 each[h] | 10 | 0.81 |
| 528 | 4.67 each[h] | 10 | 0.78 |

(Continued on next page.)

APPENDIX TABLE B-6--continued.

[a]Includes f.o.b. price, sales tax, transportation, and installation charges. Calculated using 1959 installed cost reported by Stollsteimer (1961, p. 246) adjusted by Agricultural Machinery and Equipment Wholesale Price Index (1959 = 100). For January-June, 1972, the value of this index = 144.2.

[b]Estimated on the basis of installed cost. Includes depreciation calculated according to estimated use life (10-year items, 10 percent; 15-year items, 6.67 percent); interest on invested capital calculated as $I = rA/(2)\ (t + 1/t)$ where $I$ = average annual interest cost, $r$ = interest rate estimated as 6 percent, $A$ = installed cost, and $t$ = years of use life; fixed repairs, 1.5 percent; taxes, 1.0 percent; and insurance, 1.0 percent.

[c]Same as b except fixed repairs are 4.0 percent.

[d]Estimated using 1950 installed cost reported by French, Sammet, and Bressler (1956, p. 623) adjusted by Agricultural Machinery and Equipment Wholesale Price Index (1950 = 100). For January-June, 1972, the value of this index = 186.76.

[e]Replacement cost reported by Stollsteimer (1961) adjusted by Portable Dial Scale Wholesale Price Index (1959 = 100). For January-June, 1972, the value of this index = 167.2.

[f]Replacement cost reported by Stollsteimer (1961) adjusted by Metal Commercial Furniture Wholesale Price Index (1959 = 100). For January-June, 1972, the value of this index = 125.5.

[g]Replacement cost reported by Stollsteimer (1961) adjusted by Wood Commercial Furniture Wholesale Price Index (1959 = 100). For January-June, 1972, the value of this index = 142.8.

[h]Estimate obtained from manufacturer.

[i]Estimate obtained from equipment supplier.

[j]Rental rate for 1.5 months based on monthly rental rate of 5 percent of purchase price.

[k]$L$ = length of conveyor in feed; $W$ = width of belt in inches.

[l]Replacement cost reported by Stollsteimer (1961) adjusted by Belt Conveyor Wholesale Price Index (1959 = 100). For January-June, 1972, the value of this index = 143.6.

Source: Calculated.

# APPENDIX C

## Refrigeration Requirements and Costs

The following materials pertain to three aspects of the synthesis of storage costs presented in Section V. These are (1) the estimation of refrigeration capacity required in relation to storage loading rate and capacity, (2) the estimation of storage building costs, and (3) the construction of a composite index for the adjustment of 1959 equipment replacement costs to the 1972 level. The synthesis of relationships involved in items (1) and (2) is based on a storage building module 75′ x 84′ in plan dimension, with a clear span ceiling 18 feet above floor level. (Details of construction are given in Appendix Table C–1). Storage capacity is expanded merely by replication of the basic module with the exception that the separate units have one common wall––a feature that has minor effects on both refrigeration capacity required and construction costs.

### Total Refrigeration Load in Relation to Storage Capacity

The basic conditions affecting the estimated refrigeration requirements are stated in Section V, namely, temperature of ambient air, 100° F.; of incoming fruit, 90° F.; and of storage room (and final fruit temperature), 32° F. The fruit–cooling time required is 72 hours.[1] The required refrigeration capacity may be seen in Appendix Table C–1 to include three elements: (1) the "sensible" heat removed in cooling from 90° F. to 32° F. which is a function of the rate at which the storage is loaded; (2) the heat gain through walls, roof, and floor and the heat generated in fruit respiration; and (3) miscellaneous heat gain (from motors operated within the storage, lights, opening of doors, etc.) which is computed as a percentage of (1) and (2).

The refrigeration load generated in cooling the field fruit is linear in relation to size of storage, with zero intercept and slope equal to 85,200 Btu. per room per hour. The load attributable to storage capacity also is very closely linear in relation to size of storage but with a slight intercept. For the purposes of this study, it is convenient––and introduces negligible error––to ignore the intercept and compute the slope in terms of the mean of the values given in Appendix Table C–1. This yields a slope of approximately 75,280 Btu. per room per hour. Having in mind that one room is filled to capacity in three days (so that $SC_1 = 3L$) and converting the above figures and corresponding quantities of fruit to tons of refrigeration and 1,000 pounds of fruit, respectively, refrigeration capacity, R, in relation to loading rate, L, and storage capacity, SC, may be written as

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[1] These temperatures are selected values based on available evidence and expert opinion. The length of precooling cycle is based on experimental evidence obtained in field studies by F. Gordon Mitchell, Extension Pomologist, University of California, Davis. The temperature specified for incoming fruit is based on the upper level of temperature ranges observed by Mitchell at several California shipping locations (including Lake County) and summarized in a memorandum to the authors under date of May 14, 1973. The ambient temperature is a selected level slightly above the high mean temperatures for August reported for Lake County by Kimball and Brooks (1959).

$$R = 0.173\ L + 0.050\ SC_1 + 0.014\ SC_2$$

where

$L$ = storage loading rate in 1,000 pounds per day

$SC_1$ = precool storage capacity in 1,000 pounds of fruit

and

$SC_2$ = storage capacity in excess of precooling requirements in 1,000 pounds of fruit.

**Estimated Replacement Cost of Cold Storage Building**

The investment requirements (replacement cost) for the cold storage building are determined through the use of architectural–engineering estimating procedures. These involve specification of the essential physical characteristics of the building and its construction details, the use of engineering data to determine the quantities of the various kinds of labor and materials required for fabrication and assembly, and the estimation of indirect costs. The detailed estimating data are not given here. The procedures are described in more detail in Sammet (1958) and in Pulver (1969). The results of such calculations are summarized with respect to major building elements and for buildings of three different sizes in Appendix Table C–2.

The synthesized cost points given in the table have a strongly linear relationship to building size measured in terms of floor area. This can be expressed as

$$I_s = 1{,}870 + 8{,}406\ A$$

where $I_s$ is investment in the cold storage building (1972 price level) and A is roofed area in 1,000 square feet.

**Composite Price Index––Refrigeration Equipment**

Refrigeration equipment costs (installed) were estimated in Stollsteimer (1961) based on 1959 prices obtained from refrigeration equipment engineering firms. Adjustment of those data to the 1972 price level was undertaken on the basis of a composite index constructed from selected BLS price indices and limited 1972 price information. The index developed involves the computation of a weighted average that takes account of the major elements of installed cost of refrigeration equipment, i.e., refrigeration machinery manufactured off–site; on–site materials (piping, wiring, etc.); on–site labor; and contractor's overhead. The weights applied in regard to these components are their respective amounts in engineering estimates of the current (1973) installed cost of a refrigeration system of 185 tons capacity and estimated total installed cost of $150,000 (Appendix Table C–3).

Individual component values at the 1972 prices are revalued at the 1959 level by dividing the 1972 value by the indicated index. The ratio of the 1972 total installed cost over the sum of the component costs after adjustment to the 1959 level is 158.7, and this index number is applied to the Stollsteimer 1959 data as to investment requirements in relation to refrigeration capacity. The result is the following:

$$I_r = 158.7\ (566.5 - 0.222\ R)$$

$$= 900 - 0.352\ R \qquad (75 < R < 300)$$

where $I_r$ is installed cost of complete refrigeration system in 1972 dollars per ton of refrigeration capacity and R is refrigeration capacity in tons.

Within the stated limits for R, the range of installed refrigeration equipment costs is \$874 to \$794 per ton capacity. Engineering estimates obtained in June, 1973, indicated an installed cost of \$800 to \$1,000 per ton capacity, with the applicable figure for seasonal fruit cold storage operations toward the low side of this range.[1] With allowance for price advances of roughly 5 percent during the 1972–73 Phase III governmental price constraint policy, the current price quotations are consistent with the 1959 figures adjusted to 1972. The 1972 price data were, however, not adequate for estimation of the relation between installed cost per ton and refrigeration capacity used; therefore, the adjusted 1959 relationship is used.

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[1] This reflects prevailing practice in the purchase of facilities for highly seasonal operations (in this case, one to two months per year) which is––in industry terms––to "buy power" rather than fixed equipment. The engineering consequence is lower equipment investment, less efficient operating performance, and higher power usage.

APPENDIX TABLE C-1

Synthesis of Cold Storage Refrigeration Capacity Requirements in Relation to Fruit Loading Rate and Storage Capacity[a]
Lake County, California, 1972

| Item | Refrigeration load in relation to size of storage[b] | | | |
|---|---|---|---|---|
| | One room (61.5 tons of fruit) | Two rooms (123.0 tons of fruit) | Three rooms (184.5 tons of fruit) | Four rooms (246.0 tons of fruit) |
| | Btu per hour | | | |
| Refrigeration load related to storage loading rate[c] | | | | |
| Sensible heat | 85,200 | 170,400 | 255,600 | 340,800 |
| Refrigeration load related to storage capacity[d] | | | | |
| Heat gain: Surfaces[e] | 43,429 | 85,508 | 127,587 | 169,666 |
| Respiration[f] | 17,261 | 34,200 | 51,500 | 68,400 |
| Subtotal | 60,690 | 119,728 | 179,087 | 238,066 |
| Miscellaneous[g] | 14,590 | 29,013 | 43,469 | 57,887 |
| Total | 75,200 | 148,741 | 222,566 | 295,953 |

[a]Estimated Btu refrigeration requirements are transformed into the standard measure of refrigeration capacity on the basis that 1 ton of refrigeration is the equivalent of the cooling rate obtained in melting 1 ton of ice in 24 hours, i.e., 1 ton of refrigeration = 288,000 Btu of cooling per 24 hours or 12,000 Btu per hour.

[b]Capacity per room is estimated on the basis of 6,300 square feet of floor area (dimensions of room, 75 x 84 feet, with 18-foot ceiling clearance) and the following floor area requirements in 1,000 square feet per ton of fruit stored: fruit packed in standard box, 0.00881; fruit in fiber cartons, 0.01175; and fruit in field bins, 0.00652. (These space requirements are based on the provision of a 12-foot wide center aisle for fork truck operation.)

Data on specific heat and heat of respiration of pears are taken from Lutz and Hardenburg (1968); on heat conductivities of building materials used in estimating heat-flow rates through building surfaces, from Barre and Sammet (1950).

[c]Sensible heat load in Btu per 24 honrs, $H_w$, is estimated as $H_w = w(S_p)\ (T_o - T_i)$

where

$w$ = pounds of fruit cooled

$S_p$ = specific heat of pears = 0.86

$T_o$ = incoming fruit temperature = $90^\circ$ F.

and

$T_i$ = final fruit (and room temperature) = $32^\circ$ F.

With a three-day cooling cycle and constant loading rate per day, L, the "effective" weight of fruit being cooled at full operation is W = 3L.

[d]Estimated holding refrigeration load for storage in excess of precool requirements is based on the heat gain through surfaces, plus heat of respiration at $32^\circ$ F., plus 10 percent miscellaneous = 0.033 tons of refrigeration per ton of storage capacity.

[e]Heat gain through building surfaces in Btu per 24 hours = $24\ [A_s(k)\ (T_o - T_i)]$ where $A_s$ = surface (walls, ceiling, and floor) in square feet and k = heat conductivity in Btu per square foot per hour per degree F. temperature difference and is computed on the basis of the construction detail involved and engineering heat-flow data for the componenet building materials (for walls, $k_w = 0.043$; for ceiling, $k_c = 0.026$; and for floor, $k_f = 0.100$); $T_o$ = outdoor temperature = $100^\circ$ F.; and $T_i$ = inside temperature = $32^\circ$ F.

[f]Heat of respiration is estimated by interpolation of respiration and heat generation rates in relation to temperature as published in Lutz and Hardenburg (1968).

[g]Miscellaneous heat gain is estimated as 10 percent of the sum of refrigeration load attributable to sensible heat removal and heat gain related to storage capacity (a selected percentage based on estimates of fruit cold storage refrigeration requirements) given in Hukill and Smith (1946).

Source: Computed.

APPENDIX TABLE C-2

Estimated Replacement Costs for Cold Storage Buildings in Relation to Floor Area
Lake County, California 1972

| Item | Unit cost[b] | Total quantity[a] Building A | Building B | Building C | Total cost Building A | Building B | Building C |
|---|---|---|---|---|---|---|---|
| | dollars per 1,000 square feet | 1,000 square feet | | | 1,000 dollars | | |
| 1. Grading | 38 | 6.3 | 12.6 | 18.9 | .24 | .48 | .72 |
| 2. Floor | 734 | 6.3 | 12.6 | 18.9 | 4.62 | 9.25 | 13.87 |
| 3. Wall exterior | 1,825 | 5.9 | 9.9 | 14.0 | 10.77 | 18.07 | 25.55 |
| 4. Wall interior | 1,530 | 0.0 | 1.0 | 2.0 | .00 | 1.53 | 3.06 |
| 5. Ceiling | 886 | 6.3 | 12.6 | 18.9 | 5.58 | 11.16 | 16.75 |
| 6. Roof and frame | 1,861 | 6.3 | 12.6 | 18.9 | 11.72 | 23.45 | 35.18 |
| 7. Insulation | | | | | | | |
| Ceiling | 475 | 6.3 | 12.6 | 18.9 | 2.99 | 5.98 | 8.98 |
| Walls | 400 | 5.9 | 10.9 | 16.0 | 2.36 | 4.36 | 6.40 |
| | dollars per unit | number of units | | | 1,000 dollars | | |
| 8. Electrical | | | | | | | |
| Lights | 67 | 6 | 12 | 20 | .40 | .80 | 1.34 |
| Outlets | 67 | 4 | 6 | 8 | .27 | .40 | .54 |
| 9. Ventilators | 192 | 2 | 4 | 6 | .38 | .77 | 1.15 |
| 10. Doors | | | | | | | |
| Electric | 4,685 | 1 | 2 | 3 | 4.68 | 9.37 | 14.06 |
| Standard | 631 | 1 | 3 | 5 | .63 | 1.89 | 3.16 |
| 11. Total direct cost | | | | | 44.64 | 87.51 | 130.76 |
| 12. Total indirect cost[c] | | | | | 10.27 | 20.13 | 30.07 |
| 13. Grand total cost | | | | | 54.91 | 107.64 | 160.83 |

[a]Building A is a one-room storage containing 6,300 square feet of floor space, Building B is a two-room storage containing 12,600 square feet of floor space, while Building C is a three-room storage containing 18,900 square feet of floor space. All three buildings are assumed to be of wood frame construction with 18 feet of clearance below the roof truss; exterior walls are wood frame with exterior surface consisting of 5/8-inch thick exterior-grade plywood and interior surface of 3/8-inch thick interior-grade plywood; exterior and interior surfaces are painted two coats. The roof is a roll roof on 5/8-inch plywood sheeting. A ceiling is provided to facilitate the installation of room insulation. Insulation is 6 inches of fiberglass in walls and 9-1/2 inches in ceiling and is provided with a vapor seal. Electric doors are 7 feet wide and 9 feet high.

[b]Costs in components 1 through 6 are based upon estimated requirements for labor and materials in these categories for this type of construction as developed by Sammet (1958) and converted to costs by application of 1972 prices. Cost rates for components 7 through 10 are based upon 1959 prices obtained from building contractors and adjusted to the 1972 price level by use of a building cost index (see Appendix Table C-3 for development index).

[c]Indirect costs are estimated as 23 percent of total direct costs and include allowance for engineering and architectural fees, contractor's overhead and profit, and contingencies.

Source: Computed.

APPENDIX TABLE C-3

Computation of the Composite Price Index for the Installed Cost of Refrigeration Equipment Lake County, California, 1972

| Item | Value base 1972[a] | 1972 index 1959 = 100 | Value weight adjusted to 1959 level |
|---|---|---|---|
| | 1,000 dollars | | 1,000 dollars |
| Machinery | 90.0 | 148.9[b] | 60.4 |
| Materials (on site) | 15.0 | 148.6[c] | 10.1 |
| Labor (on site) | 35.0 | 202.4[d] | 17.3 |
| Contractor (overhead and profit) | 10.0 | 150.0[e] | 6.7 |
| Total[f] | 150.0 | | 94.5 |

[a]Engineering estimates, 1972, regarding the precooling installation of 185 tons capacity (building costs excluded).

[b]BLS 1972 index for "pumps and compressors" adjusted to 1959 = 100.

[c]Simple average of BLS 1972 wholesale price indices for "brass fittings," "iron and steel," and "wire and cable" (used as proxies, unweighted, for on-site materials used).

[d]Computed index consisting of the ratio of 1972 over 1959 estimated values of skilled labor required in the construction of a model packinghouse (I = 42.9/21.2 = 202.4 expressed as a percentage).

[e]Average index of packinghouse construction materials used as proxy.

[f]Composite index (1959 = 100) = (150/94.5) 100 = 158.7.

Source: Computed.

# APPENDIX D

## Assembly Prices and Costs

The cost equations for orchard–to–plant assembly operations given in Section III were estimated by means of cost synthesis. This involved the development of a model orchard layout representative of conditions encountered in the orchard–loading operations and the use of production standards obtained in earlier studies to estimate the quantities of labor, equipment, and other inputs required at selected rates of output and hauling distances, and with alternative assembly methods.[1] Current (1972) factor prices were used in converting these physical input–output data to costs.

The model orchard layout involved the following specifications.

### Orchard Conditions

Orchard drive rows are assumed to be four tree rows apart and to be wide enough for the passage of the following pieces of equipment (maximum load, two bins high): a 2½–ton flatbed truck, a tractor–drawn orchard trailer, and a tractor with a mounted forklift attachment.

Bins for picked fruit are set at 40–foot intervals on either side of the drive row.

Empty bins are distributed in the drive row immediately adjacent to the one from which full bins are to be removed, and it is assumed that 25 percent of the empty bins must be respotted from their initial locations in the orchard––on the average, a distance of 100 feet.

The loading area required for certain handling methods is located 250 feet from the end of the drive row from which full containers are to be removed. (A loading area consists of any open area approximately 75 feet square that is reasonably level. More than one loading area is provided in a large orchard.)

Transportation labor is used only in orchard–to–plant transportation. No use on supplemental jobs is considered.

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[1] For production standards development and sources, see Stollsteimer (1960).

**Packinghouse Receiving**

Forklift equipment is available for unloading the bins.

The average time spent at the plant in waiting, unloading, and loading is specified as 24 minutes per load.[1]

Within the above specifications, cost synthesis was developed with respect to the following methods:[2]

**Method 1.**——Truck: The bins are unloaded at the edge of the orchard with a tractor forklift, and this equipment is used to distribute empty bins in the orchard and to move filled bins to the loading area. Full bins are either loaded directly onto the truck or spotted in the loading area for later reloading. Normal capacity of truck: 12 bins stacked 2 high.

**Method 2.**——Trailer (low–bed) for highway transport: This method differs from method 1 only to the extent that a low–bed, tractor–drawn trailer (three trailers of 4–bin capacity per unit) is used for the orchard–to–plant haul.

**Method 3.**——Trailer (low–bed) for highway transport: The same type of highway trailer is used as in method 2. The orchard bin–handling operations are, however, performed with a utility carrier, a device with a maximum 18–inch lift that is attachable to tractors with a three–point hitch system. With limited lift capability of the utility carrier, the highway trailer can be loaded only one bin high.

**Method 4.**——Trailer (low–bed) for highway transport: With this method the bins are left on orchard trailers while being filled by the pickers. Highway transport load is, as in method 3, limited to one bin high.

The basic production standards data given in Appendix Table D–1 and estimates of equipment fixed costs required in the computation of annual costs are given in Appendix Table D–2. These data were used in conjunction with the model orchard layout to estimate crew and equipment requirements with each method. These results and the related cost calculations for method 1 are given in Table 6, for methods 2 and 3 in Appendix Table D–3, and for method 4 in Appendix Tables D–4 and D–5.

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[1] As reported in Sammet (1952).

[2] Not all possible variations in method are included, but the above range is sufficient to permit estimation of "efficient" cost relationships in the orchard–to–plant assembly operations. In some instances alternative orchard–handling procedures with the above methods were considered; and the least–cost alternative was chosen that minimizes the combined orchard–handling and highway transportation costs.

APPENDIX TABLE D-1

General Description and Time Requirements for Each of the Basic Bin-Handling Operations Lake County, California, 1972

| General nature of operation | Unit time |
|---|---|
| | minutes |
| <u>Engage bin</u> | |
| Engage forks of forklift in pallet attached to bin; raise and tilt slightly in preparation for travel | |
| In transfer area | .172 |
| In orchard | .197 |
| On truck or trailer | .173 |
| <u>Release bin</u> | |
| Spot bin over release point, lower bin into position, and disengage forks | |
| In transfer area | .167 |
| In orchard | .155 |
| On truck or trailer | .442 |
| On top of another bin | .565 |
| <u>Maneuver</u> | |
| Backing, turning, and moving forward with tractor to get into position to either pick up or release bin[a] | |
| Moving bins to and from orchard | .611 |
| Loading bins | .212 |
| Unloading bins | .207 |
| <u>Move</u> | |
| Move with tractor and forklift attachment over considerable distance either in going to and from orchard or in the transfer area | |
| Moving to and from orchard | $T = .528 + .0026D$[b] |
| Moving in transfer area | $T = .266 + .0038D$[b] |

[a]The unit times shown for the maneuver element are on a per bin basis.

[b]T = time in minutes; D = total distance traveled in feet.

Source: Original data.

APENDIX TABLE D-2

Replacement Costs and Annual Fixed Charges for Equipment Used in Orchard-to-Plant Transportation, Lake County, California, 1972

| Item | Estimated use life | Replacement cost[a] | Allocation to fruit handling | | | | |
|---|---|---|---|---|---|---|---|
| | | | Proportion of total equipment use | Depreciation | Interest on investment[b] | Repairs[c] and miscellaneous expenses[d] | Total annual cost |
| | years | dollars | percent | dollars | | | |
| Tractor[e] | 10 | 3,890 | 50 | 199 | 64 | 87 | 350 |
| Truck[f] | 10 | 5,200 | 50 | 260 | 83 | 160 | 503 |
| Forklift attachment[g] | 15 | 2,340 | 100 | 157 | 75 | 41 | 273 |
| Trailer[h] | 15 | 510 | 100 | 34 | 16 | 44 | 94 |
| Utility carrier[i] | 15 | 240 | 100 | 16 | 8 | 4 | 28 |

[a]Adjusted 1972 price = 1959 price multiplied by appropriate Bureau of Labor Statistics wholesale price index adjusted to base year, 1959, using the following series: Tractor, "gasoline tractors, 35-49 h.p."; forklift attachment, "forklift, gas"; trailer and utility carrier, farm implements." Truck price represents purchase cost estimated directly at the 1972 level.

[b]Computed at 3.2 percent with 10-year use life and 3.3 percent with 15-year use life. This is equal to 6.0 percent interest on the undepreciated balance.

[c]Fixed repair charges computed at the rate of 2.0 percent of replacement costs for tractors and trailers and 1.0 percent for other equipment.

[d]Includes insurance charges at 0.75 percent of replacement costs plus license fees for trucks, tractors, and trailers.

[e]Four-wheel pneumatic tires, 28-33 h.p. (adjusted 1972 price = 1959 price x 1.44).

[f]18,000-pound gross vehicle weight, 8' x 14' flat-bed body current sales price, 1972).

[g]2,500-pound capacity, 9-foot lift (adjusted 1972 price = 1959 price x 1.46).

[h]Low-bed, pallet-type orchard trailer (adjusted 1972 price = 1959 price x 1.47).

[i]2,500-pound capacity, 18-inch lift (adjusted 1972 price = 1959 price x 1.47).

Source: Computed from original survey data.

APPENDIX TABLE D-3

Crew and Equipment Requirements and Costs in Relation to Rate of Output and Length of Haul with Method 2
Lake County, California, 1972

| Handling method and one-way hauling distance | Capacity output rate per hour | Crew required | Equipment required: Tractors | Trailers | Trucks | Forklift attachments | Utility carriers | Variable cost: Labor[a] | Equipment[b] | Fixed cost per hour[c] | Total hourly handling cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1,000 pounds | men | units | | | | | dollars | | | |
| Method 2 | | | | | | | | | | | |
| Bins--trailers | | | | | | | | | | | |
| 1 mile | 6.9 | 1 | 2 | 3 | d | 1 | 0 | 2.00 | .62 | 5.02 | 7.64 |
| | 9.0 | 2 | 2 | 3 | | 1 | 0 | 4.00 | .62 | 5.02 | 9.64 |
| | 10.5 | 2 | 2 | 6 | | 1 | 0 | 4.00 | .62 | 6.15 | 10.77 |
| | 17.4 | 3 | 3 | 6 | | 1 | 1 | 6.00 | .93 | 7.66 | 14.59 |
| 3 miles | 5.6 | 1 | 2 | 3 | | 1 | 0 | 2.00 | .62 | 5.02 | 7.64 |
| | 9.0 | 2 | 2 | 3 | | 1 | 0 | 4.00 | .62 | 5.02 | 9.64 |
| | 10.5 | 2 | 2 | 6 | | 1 | 0 | 4.00 | .62 | 6.15 | 10.77 |
| | 12.1 | 3 | 3 | 6 | | 1 | 1 | 6.00 | .93 | 7.66 | 14.59 |
| | 17.4 | 4 | 4 | 9 | | 1 | 1 | 8.00 | 1.24 | 10.19 | 19.43 |
| 5 miles | 4.7 | 1 | 2 | 3 | | 1 | 0 | 2.00 | .62 | 5.02 | 7.64 |
| | 7.0 | 2 | 2 | 3 | | 1 | 0 | 4.00 | .62 | 5.02 | 9.64 |
| | 8.7 | 2 | 2 | 6 | | 1 | 0 | 4.00 | .62 | 6.15 | 10.77 |
| | 10.5 | 3 | 3 | 9 | | 1 | 0 | 6.00 | .93 | 8.68 | 15.61 |
| | 17.3 | 4 | 3 | 9 | | 1 | 1 | 8.00 | .93 | 8.68 | 17.61 |
| 10 miles | 3.4 | 1 | 2 | 3 | | 1 | 0 | 2.00 | .62 | 5.02 | 7.64 |
| | 4.4 | 2 | 2 | 3 | | 1 | 0 | 4.00 | .62 | 5.02 | 9.64 |
| | 5.0 | 2 | 2 | 6 | | 1 | 0 | 4.00 | .62 | 6.15 | 10.77 |
| | 10.2 | 3 | 3 | 9 | | 1 | 0 | 6.00 | .93 | 8.68 | 15.61 |
| | 15.1 | 5 | 5 | 12 | | 1 | 1 | 10.00 | 1.55 | 12.72 | 24.27 |

(Continued on next page.)

APPENDIX TABLE D-3--continued.

| Handling method and one-way hauling distance | Capacity output rate per hour | Crew required | Equipment required: Tractors | Trailers | Trucks | Forklift attachments | Utility carriers | Variable cost: Labor[a] | Equipment[b] | Fixed cost per hour[c] | Total hourly handling cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1,000 pounds | men | units | | | | | dollars | | | |
| Method 3 | | | | | | | | | | | |
| Bins handled with a utility carrier | | | | | | | | | | | |
| 1 mile | 4.3 | 1 | 2 | 3 | | 0 | 1 | 2.00 | .62 | 4.04 | 6.66 |
| | 6.0 | 2 | 2 | 3 | | 0 | 1 | 4.00 | .62 | 4.04 | 8.66 |
| | 7.5 | 2 | 2 | 6 | | 0 | 1 | 4.00 | .62 | 5.17 | 9.79 |
| | 10.1 | 3 | 3 | 6 | | 0 | 2 | 6.00 | .93 | 6.68 | 13.61 |
| | 12.1 | 4 | 4 | 6 | | 0 | 2 | 8.00 | 1.24 | 8.08 | 17.32 |
| | 15.0 | 4 | 4 | 9 | | 0 | 2 | 8.00 | 1.24 | 9.21 | 18.45 |
| 3 miles | 3.4 | 1 | 2 | 3 | | 0 | 1 | 2.00 | .62 | 4.04 | 6.66 |
| | 4.5 | 2 | 2 | 3 | | 0 | 1 | 4.00 | .62 | 4.04 | 8.66 |
| | 6.0 | 2 | 2 | 6 | | 0 | 1 | 4.00 | .62 | 5.17 | 9.79 |
| | 7.5 | 3 | 3 | 9 | | 0 | 1 | 6.00 | .93 | 7.70 | 14.63 |
| | 12.1 | 4 | 4 | 9 | | 0 | 2 | 8.00 | 1.24 | 9.21 | 18.45 |
| | 15.0 | 5 | 5 | 9 | | 0 | 2 | 10.00 | 1.55 | 10.61 | 22.16 |
| 5 miles | 2.7 | 1 | 2 | 3 | | 0 | 1 | 2.00 | .62 | 4.04 | 6.66 |
| | 4.3 | 2 | 2 | 6 | | 0 | 1 | 4.00 | .62 | 5.17 | 9.79 |
| | 5.2 | 3 | 3 | 9 | | 0 | 1 | 6.00 | .93 | 7.70 | 14.63 |
| | 7.5 | 3 | 3 | 9 | | 0 | 1 | 6.00 | .93 | 7.70 | 14.63 |
| | 8.7 | 4 | 4 | 9 | | 0 | 2 | 8.00 | 1.24 | 9.21 | 18.45 |
| | 13.0 | 5 | 5 | 9 | | 0 | 2 | 10.00 | 1.55 | 10.61 | 22.16 |
| 10 miles | 3.6 | 3 | 3 | 6 | | 0 | 1 | 6.00 | .93 | 6.57 | 13.50 |
| | 5.0 | 3 | 3 | 9 | | 0 | 1 | 6.00 | .93 | 7.70 | 14.63 |
| | 7.5 | 4 | 4 | 9 | | 0 | 1 | 8.00 | 1.24 | 9.10 | 18.34 |
| | 10.1 | 6 | 6 | 15 | | 0 | 2 | 12.00 | 1.86 | 14.26 | 28.12 |
| | 12.6 | 7 | 7 | 18 | | 0 | 2 | 14.00 | 2.17 | 16.79 | 32.96 |

[a]Based on a wage rate of $2.00 per hour.

[b]Includes 28 cents for fuel and oil and 3 cents for minor repairs per hour of truck or tractor operation.

[c]Based on the annual fixed charges per equipment unit shown in Appendix Table D-2, a 250-hour operating season, and the number of units specified in this table.

[d]Blanks indicate this equipment not used with this method.

Source: Computed.

APPENDIX TABLE D-4

Man-Minutes Required Per Bin in Orchard and At-Plant Operations with Method 4 (Bins Filled on Orchard Trailers) in Relation to Number of Trailers Hauled Per Trip to Plant
Lake County, California, 1972

| Operation | Number of trailers hauled per trip to the plant | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| | man-minutes per bin | | |
| Move trailers between transfer area and orchard | 3.92 | 3.22 | 2.99 |
| Hook and unhook trailers | 1.00 | 1.25 | 1.33 |
| Unavoidable delay and wait | 1.25 | 1.12 | 1.08 |
| Gross orchard time per bin | 6.17 | 5.59 | 5.40 |
| Gross plant time per bin | 8.57 | 5.34 | 3.99 |

Source: Original survey data.

APPENDIX TABLE D-5

Crew and Equipment Requirements and Costs in Relation to Rate of Output and Length of Haul When Bins Are Handled by Means of Method 4 (Bins Filled Directly on Orchard Trailers) Lake County, California, 1972

| One-way hauling distance | Picking rate per hour | Crew required | Equipment required | | Variable cost | | Fixed cost[c] | Total handling cost[d] |
|---|---|---|---|---|---|---|---|---|
| | | | Tractors | Trailers | Labor[a] | Equipment[b] | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | 1,000 pounds | men | units | | dollars per hour | | | |
| 1 mile | 2.7 | 1 | 1 | 3 | 2.00 | .31 | 2.53 | 4.84 |
| | 4.0 | 1 | 1 | 4 | 2.00 | .31 | 2.90 | 5.21 |
| | 5.4 | 2 | 2 | 6 | 4.00 | .62 | 5.06 | 9.68 |
| | 6.7 | 2 | 2 | 8 | 4.00 | .62 | 5.81 | 10.43 |
| | 8.7 | 2 | 2 | 10 | 4.00 | .62 | 6.56 | 11.18 |
| | 10.1 | 2 | 2 | 12 | 4.00 | .62 | 7.31 | 11.93 |
| | 12.1 | 3 | 3 | 14 | 6.00 | .93 | 9.46 | 16.39 |
| | 13.4 | 3 | 3 | 15 | 6.00 | .93 | 9.84 | 16.77 |
| 3 miles | 3.0 | 1 | 1 | 5 | 2.00 | .31 | 3.28 | 5.59 |
| | 5.4 | 2 | 2 | 6 | 4.00 | .62 | 5.06 | 9.68 |
| | 6.7 | 2 | 2 | 11 | 4.00 | .62 | 6.94 | 11.56 |
| | 8.7 | 3 | 3 | 13 | 6.00 | .93 | 9.09 | 16.02 |
| | 10.1 | 3 | 3 | 15 | 6.00 | .93 | 9.84 | 16.77 |
| | 12.1 | 4 | 4 | 18 | 8.00 | 1.24 | 12.37 | 21.61 |
| | 12.8 | 4 | 4 | 20 | 8.00 | 1.24 | 13.12 | 22.36 |
| 5 miles | 2.7 | 1 | 1 | 6 | 2.00 | .31 | 3.66 | 5.97 |
| | 5.4 | 2 | 2 | 10 | 4.00 | .64 | 6.56 | 11.20 |
| | 6.7 | 3 | 3 | 11 | 6.00 | .93 | 8.34 | 15.27 |
| | 8.7 | 3 | 3 | 13 | 6.00 | .93 | 9.09 | 16.02 |
| | 10.1 | 4 | 4 | 16 | 8.00 | 1.24 | 11.62 | 20.86 |
| | 12.1 | 4 | 4 | 20 | 8.00 | 1.24 | 13.12 | 22.36 |
| | 12.8 | 5 | 5 | 21 | 10.00 | 1.55 | 14.90 | 26.45 |
| 10 miles | 3.0 | 2 | 2 | 7 | 4.00 | .62 | 5.43 | 10.05 |
| | 4.4 | 3 | 3 | 9 | 6.00 | .93 | 7.58 | 14.51 |
| | 6.7 | 4 | 4 | 15 | 8.00 | 1.24 | 11.24 | 20.48 |
| | 8.7 | 5 | 5 | 20 | 10.00 | 1.55 | 14.52 | 26.07 |
| | 10.1 | 5 | 5 | 23 | 10.00 | 1.55 | 15.65 | 27.20 |
| | 11.4 | 6 | 6 | 26 | 12.00 | 1.86 | 18.18 | 32.04 |
| | 12.8 | 7 | 7 | 29 | 14.00 | 2.17 | 20.70 | 36.87 |

[a]Based on wage rate of $2.00 per hour.

[b]Includes 28 cents for fuel and oil and 3 cents for minor repairs per hour of truck or tractor operation.

[c]Based on the annual fixed charges per equipment unit shown in Appendix Table D-2, a 250-hour operating season, and the number of units specified in this table.

[d]Bins converted to lug equivalent at the rate of 24 lugs per bin.

Source: Computed.

APPENDIX TABLE E

Relative Daily Receiving Rates in Various Seasons at Six Firms Which Operated Pear Packing Facilities
Lake County, California, 1945-1959

| Day of season | Plant No. I | | | | | | | | | | | Plant No. II | | Plant No. III | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1948 | 1949 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1950 | 1959 | 1945 | 1949 | 1950 | 1951 | 1952 | 1954 | 1956 | 1957 | 1958 | 1959 |
| | percent of mean daily receiving rate[a] | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 95 | 21 | 21 | 8 | 13 | 1 | 8 | 1 | 26 | 2 | 41 | 6 | 2 | 30 | 52 | 31 | 68 | 16 | 13 | 17 | 9 | 11 | 17 |
| 2 | 83 | 28 | 36 | 27 | 35 | 4 | 36 | 15 | 41 | 7 | 34 | 8 | 15 | 56 | 53 | 39 | 103 | 59 | 34 | 22 | 4 | 18 | 24 |
| 3 | 78 | 38 | 72 | 34 | 55 | 20 | 44 | 20 | 73 | 2 | 75 | 30 | 32 | 29 | 63 | 30 | 84 | 75 | 84 | 53 | 23 | 18 | 48 |
| 4 | 107 | 47 | 84 | 66 | 86 | 38 | 40 | 20 | 111 | 25 | 100 | 56 | 42 | 50 | 110 | 89 | 112 | 96 | 56 | 82 | 37 | 37 | 56 |
| 5 | 96 | 68 | 92 | 89 | 125 | 53 | 74 | 49 | 135 | 50 | 84 | 53 | 40 | 91 | 77 | 118 | 92 | 63 | 110 | 77 | 90 | 65 | 74 |
| 6 | 54 | 94 | 106 | 95 | 133 | 42 | 99 | 85 | 136 | 72 | 124 | 94 | 80 | 85 | 59 | 147 | 77 | 99 | 116 | 99 | 93 | 83 | 81 |
| 7 | 55 | 101 | 99 | 98 | 132 | 84 | 114 | 101 | 143 | 94 | 139 | 107 | 105 | 64 | 86 | 158 | 99 | 95 | 136 | 92 | 101 | 99 | 127 |
| 8 | 81 | 121 | 105 | 97 | 129 | 112 | 114 | 109 | 98 | 111 | 151 | 92 | 119 | 43 | 112 | 113 | 111 | 100 | 91 | 68 | 112 | 129 | 122 |
| 9 | 70 | 120 | 126 | 86 | 119 | 117 | 133 | 106 | 130 | 98 | 161 | 65 | 119 | 116 | 146 | 104 | 119 | 87 | 90 | 63 | 78 | 141 | 110 |
| 10 | 102 | 117 | 111 | 93 | 144 | 117 | 114 | 102 | 151 | 120 | 148 | 94 | 117 | 121 | 162 | 151 | 132 | 81 | 99 | 101 | 104 | 128 | 107 |
| 11 | 132 | 99 | 109 | 121 | 151 | 130 | 140 | 129 | 144 | 139 | 121 | 113 | 79 | 115 | 133 | 164 | 136 | 89 | 141 | 120 | 120 | 124 | 123 |
| 12 | 101 | 121 | 109 | 121 | 154 | 111 | 173 | 138 | 148 | 138 | 136 | 95 | 99 | 122 | 123 | 175 | 88 | 104 | 157 | 122 | 110 | 110 | 131 |
| 13 | 83 | 142 | 82 | 119 | 168 | 112 | 186 | 145 | 148 | 142 | 152 | 95 | 102 | 81 | 131 | 150 | 128 | 130 | 142 | 108 | 97 | 109 | 85 |
| 14 | 94 | 103 | 95 | 111 | 141 | 122 | 198 | 105 | 115 | 134 | 105 | 98 | 113 | 127 | 120 | 103 | 141 | 132 | 141 | 95 | 118 | 126 | 93 |
| 15 | 101 | 113 | 120 | 77 | 167 | 124 | 181 | 120 | 116 | 93 | 136 | 111 | 89 | 132 | 141 | 135 | 136 | 128 | 165 | 125 | 147 | 152 | 101 |
| 16 | 74 | 124 | 123 | 102 | 194 | 133 | 109 | 125 | 144 | 123 | 89 | 138 | 119 | 110 | 131 | 164 | 120 | 113 | 144 | 153 | 175 | 151 | 133 |
| 17 | 74 | 120 | 126 | 118 | 185 | 122 | 136 | 127 | 138 | 136 | 164 | 157 | 114 | 119 | 114 | 152 | 105 | 144 | 82 | 152 | 196 | 178 | 161 |
| 18 | 99 | 116 | 108 | 124 | 192 | 117 | 173 | 149 | 143 | 129 | 148 | 163 | 115 | 113 | 154 | 142 | 94 | 134 | 95 | 168 | 183 | 150 | 149 |
| 19 | 63 | 113 | 94 | 128 | 165 | 133 | 172 | 154 | 112 | 138 | 137 | 146 | 148 | 89 | 185 | 142 | 92 | 154 | 131 | 154 | 157 | 161 | 166 |
| 20 | 124 | 118 | 110 | 129 | 154 | 130 | 151 | 137 | 102 | 137 | 142 | 141 | 159 | 125 | 148 | 103 | 124 | 148 | 86 | 97 | 136 | 132 | 165 |
| 21 | 123 | 119 | 134 | 118 | 98 | 66 | 136 | 121 | 108 | 110 | 129 | 78 | 165 | 116 | 143 | 128 | 111 | 130 | 146 | 120 | 141 | 110 | 156 |
| 22 | 122 | 109 | 130 | 106 | 99 | 102 | 107 | 102 | 122 | 121 | 67 | 111 | 155 | 124 | 155 | 125 | 85 | 149 | 139 | 146 | 165 | 139 | 152 |
| 23 | 151 | 121 | 123 | 123 | 88 | 51 | 72 | 111 | 121 | 131 | 110 | 140 | 136 | 110 | 121 | 110 | 115 | 119 | 145 | 146 | 146 | 122 | 146 |
| 24 | 140 | 129 | 120 | 125 | 43 | 120 | 74 | 114 | 108 | 143 | 95 | 138 | 132 | 103 | 48 | 55 | 114 | 128 | 149 | 130 | 133 | 109 | 108 |
| 25 | 158 | 130 | 105 | 126 | 26 | 127 | 71 | 120 | 74 | 121 | 56 | 128 | 140 | 103 | 100 | 44 | 59 | 68 | 151 | 115 | 98 | 107 | 99 |
| 26 | 142 | 128 | 93 | 121 | 3 | 67 | 62 | 128 | 48 | 122 | 53 | 123 | 150 | 100 | 67 | 67 | 91 | 97 | 83 | 106 | 78 | 124 | 55 |
| 27 | 133 | 116 | 104 | 129 | 0 | 124 | 39 | 123 | 17 | 98 | 43 | 113 | 131 | 110 | 66 | 41 | 82 | 99 | 24 | 130 | 55 | 85 | 75 |
| 28 | 92 | 111 | 97 | 115 | 0 | 123 | 25 | 107 | 16 | 86 | 37 | 68 | 100 | 104 | 0 | 21 | 67 | 87 | 29 | 70 | 42 | 52 | 68 |
| 29 | 85 | 69 | 92 | 111 | 0 | 120 | 16 | 40 | 13 | 97 | 20 | 109 | 67 | 102 | 0 | 0 | 67 | 54 | 18 | 57 | 32 | 28 | 64 |
| 30 | 88 | 45 | 78 | 85 | 0 | 116 | 6 | 95 | 18 | 80 | 0 | 128 | 21 | 87 | 0 | 0 | 32 | 19 | 0 | 9 | 23 | 0 | 63 |

(Continued on next page.)

APPENDIX TABLE E--continued.

| Day of season | Plant No. IV | | | | Plant No. V | | | | | Plant No. VI | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1956 | 1957 | 1958 | 1959 | 1954 | 1956 | 1957 | 1958 | 1959 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 |
| | percent of mean daily receiving rate[a] | | | | | | | | | | | | | | |
| 1 | 36 | 12 | 9 | 78 | 25 | 3 | 4 | 3 | 1 | 2 | 4 | 26 | 58 | 12 | 15 |
| 2 | 48 | 65 | 32 | 55 | 46 | 9 | 10 | 5 | 9 | 28 | 15 | 54 | 53 | 13 | 45 |
| 3 | 73 | 82 | 60 | 67 | 54 | 23 | 19 | 4 | 11 | 15 | 26 | 61 | 54 | 38 | 56 |
| 4 | 107 | 93 | 92 | 51 | 56 | 40 | 20 | 4 | 23 | 35 | 53 | 61 | 60 | 34 | 61 |
| 5 | 126 | 98 | 107 | 100 | 70 | 58 | 20 | 16 | 32 | 24 | 80 | 50 | 67 | 57 | 87 |
| 6 | 91 | 124 | 97 | 102 | 78 | 71 | 51 | 33 | 31 | 29 | 204 | 83 | 83 | 105 | 94 |
| 7 | 98 | 110 | 134 | 116 | 81 | 82 | 89 | 42 | 50 | 78 | 82 | 86 | 99 | 122 | 62 |
| 8 | 106 | 128 | 120 | 106 | 97 | 78 | 80 | 67 | 81 | 73 | 196 | 115 | 171 | 138 | 92 |
| 9 | 66 | 138 | 108 | 77 | 106 | 84 | 90 | 83 | 98 | 95 | 208 | 116 | 89 | 151 | 118 |
| 10 | 74 | 138 | 113 | 106 | 110 | 76 | 84 | 85 | 105 | 99 | 162 | 121 | 152 | 135 | 109 |
| 11 | 92 | 100 | 105 | 138 | 121 | 73 | 69 | 81 | 109 | 57 | 165 | 154 | 165 | 141 | 121 |
| 12 | 98 | 112 | 111 | 125 | 124 | 106 | 91 | 102 | 119 | 67 | 124 | 155 | 143 | 153 | 128 |
| 13 | 128 | 116 | 116 | 78 | 124 | 132 | 138 | 103 | 94 | 100 | 229 | 159 | 144 | 161 | 68 |
| 14 | 143 | 121 | 132 | 101 | 197 | 155 | 161 | 115 | 125 | 99 | 224 | 144 | 135 | 169 | 94 |
| 15 | 148 | 164 | 113 | 103 | 170 | 168 | 164 | 140 | 138 | 130 | 183 | 169 | 95 | 125 | 121 |
| 16 | 160 | 117 | 133 | 94 | 175 | 155 | 139 | 114 | 147 | 86 | 173 | 161 | 124 | 116 | 111 |
| 17 | 153 | 178 | 107 | 158 | 189 | 162 | 171 | 143 | 122 | 84 | 64 | 158 | 126 | 144 | 110 |
| 18 | 112 | 154 | 135 | 152 | 152 | 195 | 226 | 172 | 92 | 138 | 119 | 165 | 113 | 180 | 134 |
| 19 | 118 | 157 | 131 | 144 | 154 | 145 | 160 | 153 | 96 | 152 | 140 | 151 | 104 | 168 | 153 |
| 20 | 112 | 159 | 131 | 144 | 202 | 176 | 175 | 141 | 148 | 153 | 142 | 145 | 124 | 167 | 152 |
| 21 | 147 | 155 | 144 | 128 | 139 | 183 | 198 | 175 | 101 | 168 | 80 | 134 | 102 | 142 | 121 |
| 22 | 147 | 155 | 144 | 128 | 148 | 174 | 161 | 136 | 155 | 125 | 49 | 100 | 96 | 163 | 117 |
| 23 | 142 | 120 | 121 | 107 | 101 | 174 | 146 | 126 | 155 | 195 | 23 | 105 | 98 | 142 | 126 |
| 24 | 114 | 76 | 67 | 115 | 129 | 162 | 188 | 141 | 132 | 146 | 59 | 102 | 137 | 93 | 117 |
| 25 | 142 | 76 | 98 | 98 | 86 | 155 | 171 | 156 | 114 | 158 | 37 | 109 | 104 | 75 | 92 |
| 26 | 56 | 66 | 127 | 114 | 47 | 116 | 103 | 153 | 145 | 156 | 26 | 76 | 126 | 54 | 113 |
| 27 | 85 | 33 | 109 | 97 | 18 | 43 | 45 | 153 | 139 | 172 | 26 | 36 | 147 | 0 | 112 |
| 28 | 70 | 0 | 72 | 83 | 0 | 0 | 10 | 89 | 150 | 139 | 46 | 4 | 79 | 0 | 106 |
| 29 | 10 | 0 | 55 | 35 | 0 | 0 | 3 | 170 | 126 | 147 | 35 | 0 | 98 | 0 | 139 |
| 30 | 0 | 0 | 0 | 48 | 0 | 0 | 10 | 95 | 93 | 41 | 17 | 0 | 82 | 0 | 22 |

[a]Computed from actual receipts data for these plants.

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